AD-A123 537 SAFETY BENEFITS ANALYSIS OF GENERAL AVIATION COCKPIT 1/2
STANDARDIZATION(U) KAPPA SYSTEMS INC ARLINGTON VA
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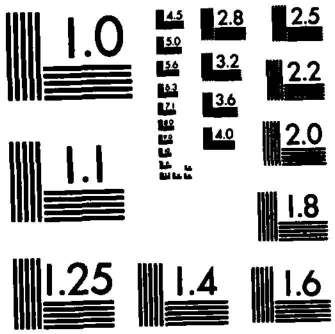
UNCLASSIFIED DTFA03-81-C-00058 F/G 1/2 NL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DOT/FAA/CT-82/143

AD A123537

Safety Benefits Analysis of General Aviation Cockpit Standardization

KAPPA Systems, Inc.
1501 Wilson Boulevard
Arlington, Virginia 22209

December 1982

Final Report

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US Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

NOTICE

Technical Report Documentation Page

1. Report No.: DOT/FAA/CT-82/143
2. Government Accession No.: AD-A123 537
3. Recipient's Catalog No.:
4. Title and Subtitle: SAFETY BENEFITS ANALYSIS OF GENERAL AVIATION COCKPIT STANDARDIZATION
5. Report Date: December 1982
6. Performing Organization Code:
7. Author(s): Bruce E. Beddow, Sidney Berger, Charles E. Roberts, Jr.
8. Performing Organization Report No.:
9. Performing Organization Name and Address: Kappa Systems, Inc., 1501 Wilson Boulevard, Arlington, Virginia 22209
10. Work Unit No. (TRAIS):
11. Contract or Grant No.: DTFA03-81-C-00058
12. Sponsoring Agency Name and Address: U.S. Department of Transportation, Federal Aviation Administration, Atlantic City Airport, New Jersey 08405
13. Type of Report and Period Covered: Final, June 1981 - September 1982
14. Sponsoring Agency Code:
15. Supplementary Notes:

16. Abstract

The purpose of this study was to assess the societal benefits that may be gained by implementation of cockpit standardization as a countermeasure to fuel mismanagement accidents and accidents involving improper operation of the powerplant and powerplant controls. The benefits are expressed as the costs of accidents which could be prevented by standardization. Detailed analyses were performed on a sample of 200 accident cases drawn from the National Transportation Safety Board files which contain 2,011 accidents in the period 1975-1979 due to the specified causes. The flight environment, aircraft and pilot characteristics, and their interrelation were fully considered in studies of accident causes. The accident pilot-group which contained many high time pilots with advanced certificates was found less qualified with regard to recent night flying and instrument flight time. Fuel systems for all makes and model aircraft of the sample were found to contain great diversity in location of components and operating modes. Powerplant controls are not as diverse in design but still do not conform totally to recommended optimization guidelines. Preventability is determined by identification of all elemental pilot errors in an accident and overlaying these on an application of standardization guidelines applied to the controls, instruments, and arrangements. Average accident costs are determined by a severity index breakdown and then carefully extrapolated to the full accident data base. Cumulative accident cost reductions are found for a 10-year future period. A proposal for alleviating the pilot non-familiarity with specific makes and models is included. In this area, an advisory approach is found preferable to certification and rating structural changes.

17. Key Words: Mismanagement of fuel; Improper operation of powerplant; Pilot error; Cockpit standardization; Pilot restriction
18. Distribution Statement: Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161
19. Security Classif. (of this report): Unclassified
20. Security Classif. (of this page): Unclassified
21. No. of Pages: 114
22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

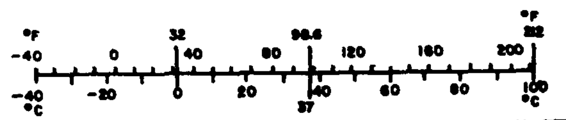
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Acknowledgement

This work was performed under contract number DTFA03-81-C-00058. KSI's Contract Technical Manager was Mr. Robert Ontiveros at the Federal Aviation Administration Technical Center at Atlantic City, New Jersey. The authors would like to acknowldge Mr. Ontiveros' continuous support throughout the period of this study and our reliance on the previous work he had completed in this subject area.

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

The project covered by this report is an analysis of general aviation accidents over the period 1975-79 where the primary causal factor of the accident is pilot error--either mismanagement of fuel or improper operation of powerplant and powerplant controls. Related secondary accident factors are also included. The purpose of the investigation is to determine which accidents might have been prevented by the application of cockpit standardization as an accident countermeasure and to derive the societal benefits in the form of reduced economic losses. Specifically, the cost savings are required at the fifth and tenth years after the standardization countermeasure implementation. An alternative countermeasure to the accidents, in the form of pilot restrictions as a means of assuring cockpit familiarity, is fully considered. It should be understood that this study is not intended to propose new guidelines for cockpit standardization.

An essential quality of the method used in the study has been the detailed examination of accident files. This led to a sampling approach by which 200 cases were drawn from the full National Transportation Safety Board (NTSB) data base of 2,011 accidents of the specified causes. An optimum allocation of variance technique was employed to assure that cost results had the maximum validity. Stratification of the full data base was performed by accident severity index and oversampling was done for fatal and severe injury categories. Otherwise the sample reproduced the required accident characteristics in all regards as, for example, pilot qualifications, flight and environmental conditions, and aircraft makes and models. After numerous case substitutions in order to construct a complete sample, ten case files from the National Transportation Safety Board (NTSB) data base were deficient; but this had only a negligible effect on the validity of the findings.

Examination of the qualifications of the accident pilots leads to some striking observations. For the most part, the pilots are highly experienced, with 87 percent having more than 100 hours of flying time. The range of 500 to over 3,000 flying hours includes one-third of the pilots. Their time in type is less impressive, and only 19 percent had more than 100 hours. Approximately 44 percent hold commercial or higher certificate, and 32 percent are instrument rated. Aircraft renters comprise 34 percent of the pilot group. In regard to recency of experience, 40 percent of the pilots had not logged any night flying time in the preceding 90-day period. Overall, the qualification picture is mixed, with the rather high totals of flying hours and the advanced certificates being offset by the low time in type, the low level of recent night flying, and by the proportion of renters. The negative aspects of the pilot qualifications may have greater influence on accidents than the positive and may constitute a problem area.

The main findings on the environment of the accidents pertain to visibility. The proportion of accidents occurring under nighttime conditions is 21 percent and under IFR (Instrument Flight Rules) conditions is 10 percent.

Aircraft makes and models appear in the accidents in roughly the same way as in previously published accident analyses. Makes/models known to be high or very high involvement aircraft appear in the rosters for fuel management or powerplant control type accidents in predictable proportions.

The fuel systems and powerplant controls were examined for all aircraft designs of the accident sample and it was found that conformity to published guidelines (Reference 10) on standardization is clearly deficient. The term standardization is used in a broad sense and includes also those features which optimize a pilot's task performance. Extreme diversity was found for the fuel systems. Selector valves are in scattered locations, some with poor accessibility. Selector patterns differ markedly. Fuel gauges are also in scattered locations; most are uncoordinated with other gauges; only a few provide a cue as to which tank is being drawn on; some serve more than one tank and require switching to read fuel quantity for the several tanks; and some are difficult to read because of position and size. Some auxiliary pump switches are unduly complicated and their location is not coordinated with respect to other fuel and powerplant controls. Powerplant controls are subject to less criticism but still contain odd locations for some actuators and lack coordination between gauges and controls. Some friction locks are not readily disengaged under emergency conditions. The need for carburetor heat is not made apparent, nor is the intensity and duration of the required heating. Manuals do not provide some of the essential instructions and warnings in an easily comprehensible way. Most of the observed standardization deficiencies appeared in the analysis of accidents for preventability determinations.

Analysis of the accidents to determine preventability proved to be a formidable task. Initial reviews were performed qualitatively for each accident and the countermeasures were assigned for standardization or pilot restriction, or both, or neither. A more objective technique was later introduced under which each elemental pilot error, based on a fault tree breakdown, was overlaid on discrepant standardization, using Federal Aviation Agency Technical Center published guidelines. This enabled the assignment of penalty points for each error contributing to the accident. An analogous method was developed for pilot restrictions.

Of the sample data base containing 200 accidents, 47 were found to be preventable by standardization and/or pilot restrictions. Of these, 35 involved mismanagement of fuel and 12 involved powerplant operation. This proportioning confirms that standardization deficiencies are more severe in fuel systems than in power controls, as found in the design examination. The powerplant control problems are dominated by icing and the related carburetor heat usage. It was additionally observed that, after a first pilot error, there were usually multiple opportunities to recover from the emergency and that the actual accident included several distinct elements of error.

The accidents preventable by standardization were put through cost analysis. All published cost estimating factors were considered leading to the value of a statistical life at $530,000 and severe injuries at $38,000. The life value as found by the value to self and others approach is higher than that found by other methods, but being most accepted in aviation accident studies, was adopted. Aircraft values are taken from the Blue Book, with damage being valued at a specified fraction of the replacement cost.

Cost results are presented for each of the standardization countermeasure accidents. Averages are determined for each level of severity. The results show that the fatalities are the dominant influence in the cost results. Also, the number of occupants in fatal accidents is crucial. The results confirm the gain in accuracy by allocation of variance.

With the averages by severity index, it is possible to take the stratified full NTSB data base and compute an average year accident cost. This is found to be $6,701,000. Then, by the introduction of new design aircraft containing standardization features, either as modifications to existing models or as new models, the accident losses would be reduced. This would be in proportion to the new designs as a fraction of the total active fleet. The data on fleet size is the current forecast and includes the effect of depressed conditions in the industry. The new design fraction is 13.7 percent at the fifth year and 36.5 percent at the tenth year. This leads to cumulative cost reductions of $1,916,400 at the fifth year and $11,257,600 at the tenth year. It is noted that the second $10 million will be realized after four additional years. Evaluation of these amounts would need to be made with respect to the costs of standardization.

A relationship was not found between general aviation safety on the one hand and aircraft sales and pilot training starts on the other. Several statistical tests were applied to the data and correlation was not established. This result was also found when aircraft sales were taken for one year behind the safety record. Aircraft sales were found to be in close correlation with real Gross National Product. New pilot starts exhibit no particular trend, but do have a substantial year to year variation.

The problem of improving pilot familiarity with his aircraft, and in particular the cockpit arrangement, was studied intensively. A solution is proposed which uses a written examination to be administered by fixed base operators. The problems and questions put to a prospective renter would force him to consult the pilot's manual and to actually manipulate certain controls. The use of the examination would not be toward disqualifying a candidate, although this could happen, but rather to show areas where a check flight ought to provide remedial help. A limited survey of fixed base operators indicates their attitude to be very positive and general acceptance could be expected. Examples of typical problems and questions for the examination are contained in the report. It is believed that the issuance of such an examination on an advisory basis could produce results promptly. This approach avoids the administrative burdens and delays that would be associated with certificate endorsements or other mandatory measures.

INTRODUCTION

Over an extended period of years, the statistical compilations of accident data pertaining to general aviation engine failure/malfunction accidents have shown that pilot mismanagement of fuel supply and improper operation of powerplant and powerplant controls are prominent causal factors. The problem has received attention from Government agencies and industry groups concerned with flight safety. However, these types of accidents continue to be frequent despite a somewhat downward trend in general aviation accidents as a rate of total flying activity.

PURPOSE.

The purpose of this study was to assess the societal benefits to be gained by the implementation of cockpit standardization as a countermeasure to fuel mismanagement accidents and accidents involving improper operation of powerplant and powerplant controls. An adequate understanding of the extent and characteristics of these cause/factors was an important step in formulating any conclusions.

BACKGROUND.

Accidents in general aviation which involve fuel mismanagement and powerplant control operation problems account for a significant percentage of the engine failure/malfunction accident population. A study by the Bureau of Safety of the Civil Aeronautics Board (CAB), based on the general aviation accidents of 1964 (Reference 1), showed the pilot to be responsible, totally or partially, for 83 percent of the occurrences. The underlying emphasis in the analysis was that many of the accidents involving pilot error were design-induced. The term includes accidents where the pilot had difficulty in recovering from an emergency, even if arising from his own mistake. Further accident analysis, performed by the National Transportation Safety Board (NTSB), covered the years 1965 through 1969 and concentrated on engine failure/malfunction (Reference 2). It was found that 19.3 percent of the engine failure accidents were caused by fuel starvation (the interruption, reduction, or complete termination of fuel flow to the engine although ample fuel for normal operation remains aboard the aircraft). For engine failure accidents occurring between 1970 and 1974, 16.8 percent were caused by fuel starvation, 13 percent by improper operation of powerplant and powerplant controls, and 25 percent by fuel mismanagement in general. A later NTSB study examined accidents of the years 1970 through 1972 (Reference 3) with the objective of identifying the causes of fuel starvation accidents and proposing remedial action. Some specific engine failure accidents included: (1) an inability to restart the engine or regain full power after exhausting one tank; (2) instructional simulation of power loss and an inability to regain full power; and, (3) improper use of powerplant controls such as the resetting of mixture control when the intention was to apply carburetor heat. The recommendations included advisories on the fuel starvation matter, flight manual improvements, and standardizing regulations applicable to powerplant controls and fuel selector valves.

In 1978, there were 306 general aviation accidents attributed to mismanagement of fuel and 110 attributed to improper operation of powerplant and powerplant controls. These accidents accounted for 6.9 percent and 2.4 percent, respectively, of the general aviation accidents occuring in 1978 for which a causal factor was assigned.

Considerable effort has been devoted to assessing the potential effectiveness of cockpit standardization (or optimization) in reducing such accidents, with specific attention focused on fuel systems standardization and cockpit design. Both the General Aviation Manufacturers Association (GAMA) and the Federal Aviation Administration (FAA) itself have explored new approaches to standardization in these areas.

The full implementation of such approaches, however, whether through rulemaking activities or voluntary compliance, requires a thorough accounting of the societal costs of accidents which might have been prevented through cockpit standardization. The main benefits are (1) reduction of: lives lost, productivity losses, and property damage; and (2) a possible increase in aircraft sales and revenue from pilot training starts that might follow from an overall reduction in general aviation accident rates.

APPROACH AND METHODOLOGY

The process of forming a working data base for the detailed accident analysis and countermeasure assignment commences with the total of all accidents compiled by the National Transportation Safety Board (NTSB). For the five year period of 1975 through 1979, the examination of the accident data establishes the characteristics to be sought for the sample of 200 cases. A statistically valid sampling procedure is formulated and the resulting subset of accidents is found to be representative in the important matters of pilot experience, accident conditions, and aircraft makes and models. The fuel systems and powerplant controls of the subject aircraft are presented as essential groundwork for the determination of accident countermeasures.

SELECTION OF CASES FROM THE NTSB DATA BASE.

Several preliminary steps were performed at the outset. Automated data processing was performed on a DEC-PDP 11/44 computer of the contractor. All general aviation accidents were extracted from the NTSB data files, since initially some air carrier cases were included. Next, all accidents where the probable cause was, or included, pilot error were extracted, using code 64 (pilot error) and cause/factor field suffixes 21 (improper operation of powerplant and powerplant controls) and 32 (mismanagement of fuel) as contained in the guide defining code classifications (Reference 4).

STRATIFICATION OF THE NTSB DATA BASE. The yield from the NTSB data base was 2,011 accidents of interest over the years 1975-79. The accidents are stratified in several ways to distinguish them by accident category. The procedure for accomplishing the stratification was:

1. Two working files within the pilot error accidents were created using code suffix 32 - mismanagement of fuel, and code suffix 21 - improper operation of powerplant and powerplant controls.

2. A sampling frame was developed based on mutually exclusive sets of accidents from the two major accident (suffix) codes. This sampling plan resulted in 60 cells since a third set was added for multiple causes/factors, specifically including these items:

   a. Diverted attention from operation of aircraft.
   b. Failed to use or incorrectly used miscellaneous equipment.
   c. Improper in-flight decisions or planning.
   d. Inadequate supervision of flight.
   e. Lack of familiarity with aircraft (model).
   f. Spontaneous, improper action.

   Within each set there were four levels of accident severity, and the breakdown over five years was performed. This result is shown in Table 1. (It may be noted that an intermediate step was taken with 180 cells but several sets of multiple cause/factor accidents did not show case variances to warrant further evaluation and a collapsing to the 60-cell matrix was performed.)

3. Each case (file number) in a cell was then assigned a sequential number for random selection. However, prior to sampling, the variance review needs to be performed for tailoring the optimized sample.

THE OPTIMIZED SAMPLE OF ACCIDENTS. The main problem in optimization is the usual one of sampling in that the sample size is much less important than assurance that the sample is an accurate representation of the total population. A sample size of 200 accident cases from the NTSB set of 2011 was the initial target and no necessity for any change was encountered. However, the necessary steps to sample cases from strata so as to minimize cost errors were taken.

Cost Variance Analysis. This analysis was performed on a partial group of the 200 cases. The cost variance per stratum was found for the cause/factor and severity levels as shown in Table 2. Two cases were randomly drawn from each cell, i.e., the 73 cases shown in Table 2 were brought up to 120 by filling the gaps and adding to the cells where only one example had previously been available. Then the year by year segregation was dropped. Standardized cost elements were used in accordance with conventional practice (Reference 5), converted to 1980 dollar values. Then, all accident costs were computed for the strata on a comparable basis. For each severity level, the standard deviation was found for 30 selected cases. Next, it was possible to use the Neyman allocation sampling formula (Reference 6) for the optimal number of cases to be drawn for each stratum. The results are shown in Table 3.

TABLE 1. STRATIFICATION OF NTSB PILOT ERROR ACCIDENTS

(Prior to Sampling)

		1975	1976	1977	1978	1979	TOTAL
MISMANAGEMENT OF FUEL ONLY	FATAL INJURY	10	9	27	26	10	82
	SERIOUS INJURY	27	32	37	36	28	160
	MINOR INJURY	60	51	43	69	51	274
	PROPERTY DAMAGE ONLY	124	105	130	143	131	633
IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS ONLY	FATAL INJURY	9	7	12	9	3	40
	SERIOUS INJURY	15	13	8	17	9	62
	MINOR INJURY	27	24	20	25	14	110
	PROPERTY DAMAGE ONLY	59	74	63	51	70	317
MULTIPLE CAUSE/ FACTORS	FATAL INJURY	16	12	10	9	5	52
	SERIOUS INJURY	8	17	10	7	11	53
	MINOR INJURY	14	15	18	9	11	67
	PROPERTY DAMAGE ONLY	39	34	43	25	20	161
	TOTAL	408	393	421	426	363	2011

TABLE 2. SAMPLE STRATIFICATION FOR COST VARIANCE ANALYSIS

MAJOR CATEGORIES	SUBCATEGORIES	ACCIDENT YEAR 1975	1976	1977	1978	1979	TOTAL
MISMANAGEMENT OF FUEL ONLY	FATAL			2	1	2	5
	SERIOUS		1	2	1		4
	MINOR	1	1	1	1		4
	PROPERTY DAMAGE ONLY	1		1	1		3
IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS ONLY	FATAL	1	2	2	2	2	9
	SERIOUS	1	2	2	2	2	9
	MINOR	2	2	2	1	2	9
	PROPERTY DAMAGE ONLY	1	2	2	2	2	9
MULTIPLE CAUSE/ FACTORS	FATAL			2	2	1	5
	SERIOUS		1		1	1	3
	MINOR	1	1	1		2	5
	PROPERTY DAMAGE ONLY		2	2	2	2	8
	TOTAL	8	14	19	16	16	73

TABLE 3. SAMPLING ALLOCATION

Accid. Severity Category	No. of Cases Available	Std. Devia. 30 Select Cases	Opt. Sample Size	Final Sample Size
Fatal	174	$693,792	115	99
Serious	275	185,798	49	42
Minor	451	15,283	7	29
Prop Dmge Only	1111	27,245	29	30
Totals	2011		200	200

The optimum allocation of accidents, as shown in the third column, was modified to produce the distribution as shown in the fourth column. The dilemma at this point was that the work performed on 120 cases had to be preserved and included 59 cases in the minor and property damage categories, i.e., about one-half of the 120 test cases. Thus, using 141 as the number of cases to be allocated, the Neyman calculation was reiterated to obtain the final sample stratification. The detailed breakdown, including cause/factor and yearly distribution, is shown in Table 4.

TABLE 4. CASE STRATIFICATION OF FINAL SAMPLE

ACCIDENT/CAUSE	ACCIDENT SEVERITY	1975	1976	1977	1978	1979	TOTAL
MISMANAGEMENT OF FUEL ONLY	Fatal	6	5	15	15	6	47
	Serious	4	5	6	5	4	24
	Minor	2	2	2	2	2	10
	Property Damage Only	2	2	2	2	2	10
Sub-Total		14	14	25	24	14	91
IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS ONLY	Fatal	5	4	7	5	2	23
	Serious	1	2	2	2	2	9
	Minor	2	2	2	2	2	10
	Property Damage Only	1	2	2	2	2	9
Sub-Total		9	10	13	11	8	51
MULTIPLE CAUSE/ FACTORS	Fatal	9	7	5	5	3	29
	Serious	1	2	2	2	2	9
	Minor	2	2	2	2	2	10
	Property Damage Only	2	2	2	2	2	10
Sub-Total		14	13	11	11	9	58
TOTAL		37	38	49	46	31	200

DISCUSSION AND RESULTS

THE SAMPLE ACCIDENT DATA BASE.

All the 200 accidents selected in the sampling process are in the category of pilot error involving mismanagement of fuel and improper operation of powerplant and powerplant controls, but otherwise substantial diversity is contained in all the elements of the accidents. In fact, by virtue of the selection procedure, a likeness of the NTSB full data base has been produced.

SEVERITY OF THE ACCIDENTS. Both human injury and aircraft damage are considered. The injury indices are: fatal, serious, minor, or none. Distribution of the injuries is shown in Table 5 where the fatal group at 49.0 percent (accidents where at least one fatality occurred) is seen to be substantial. For comparison, it may be noted that in the five-year period of 1960-64, having approximately 24,000 total general aviation accidents, the rate for fatal accidents, at 9.5 percent, is much lower. For the three-year period of 1976-78, the proportion of fatal accidents climbed to 16.6 percent. The sample does not conform to the expected distribution due to the oversampling of fatal and serious cases.

TABLE 5. ACCIDENT DISTRIBUTION BY INJURY INDEX

Mismanagement of Fuel		Improper Operation of Powerplant and Powerplant Controls		Multiple Cause Factors	
Fatal	47	Fatal	23	Fatal	29
Serious	24	Serious	9	Serious	9
Minor	10	Minor	10	Minor	10
Prop. Dmge	10	Prop. Dmge	9	Prop. Dmge	10
Subtotal	91	Subtotal	51	Subtotal	58

Aircraft Occupants Involved	
Fatalities	176
Serious Injuries	139
Minor Injuries	77
No Injuries	84
Total Persons	476

Aircraft damage is also severe in these engine failure accidents regardless of injury severity. Note in Table 6 that 52 percent of the accidents resulted in the destruction of the aircraft and 48 percent produced substantial damage. The latter category is found to require repairs at the rate of about one-third of the replacement cost which is at the lower end of the working range (Reference 7). There are no aircraft with minor damage. In addition, of the 77 accidents reporting impact severity, 62 or 80.5 percent reported severe to extreme impacts. These facts support the high degree of severity thought to be associated with these types of accidents.

TABLE 6. ACCIDENT DISTRIBUTION BY AIRCRAFT DAMAGE

MISMANAGEMENT OF FUEL			IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS		
. Destroyed	68	(48.9%)	. Destroyed	36	(59.0%)
. Substantial	71	(51.1%)	. Substantial	25	(41.0%)
. Minor	0		. Minor	0	
TOTAL	139		TOTAL	61	

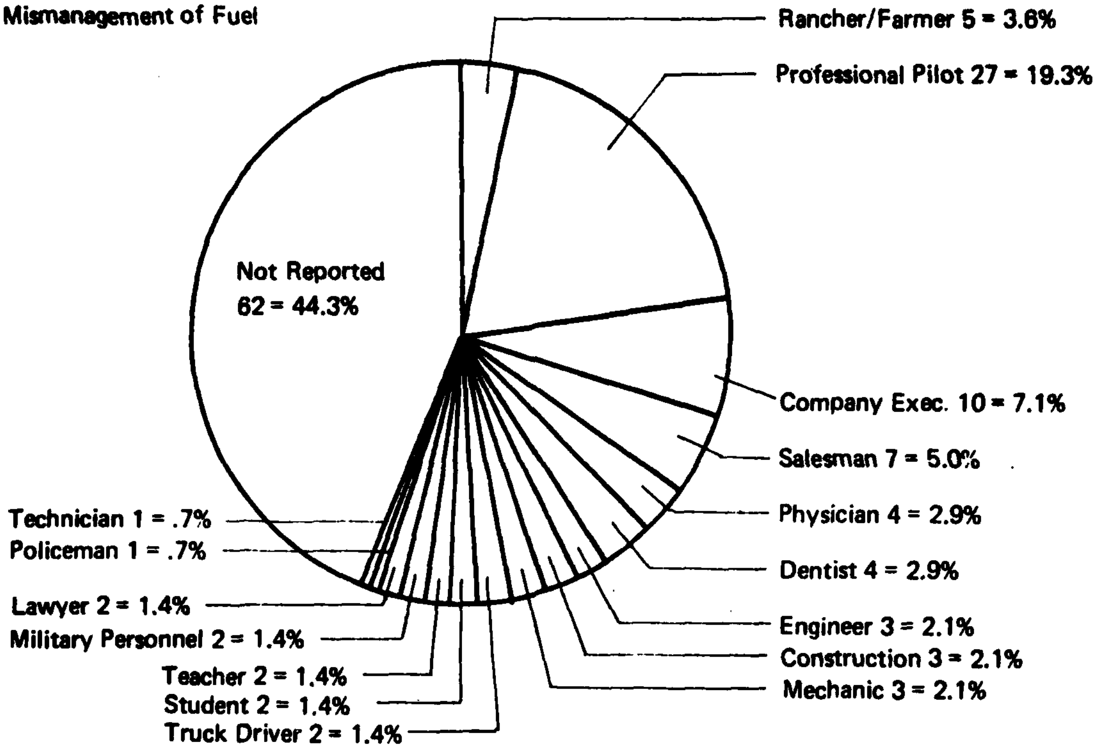
PILOT DESCRIPTION.

Occupation. The pilots involved in the accidents appear to be varied in their backgrounds and aviation experience. Their occupations indicate a reasonably high probability of competence in coping with the technical problems of flight. For example, the three groups with the highest representation include professional pilots, company executives, and trained technical personnel (engineers, mechanics, and technicians). The full breakdown is shown in Figure 1. Note that professional pilots are 20.4 percent of the total. The general impression created by this data item is that the accident pilots have a serious interest in aviation and are not likely to commit frivolous flying errors.

Pilot Total Flying Hours. The data of Figure 2 show that large numbers of experienced pilots are involved in the accidents. The groups of 501-1000 hours and 1001-3000 hours comprise more than one-third of the total. Combining all of the groups above 101 hours results in a total of 86 percent of the accidents. It is clear that these pilot error accidents are not characterized by inexperience of the pilots. This observation conforms to findings from past analyses of general aviation accidents, for example References 8 and 9.

Pilot Time in Aircraft Type. There is a significant lowering of pilot experience in the type of aircraft involved in the accident as compared to total flying time. These data are shown in Figure 3. For the range of less than 100 hours of total pilot experience, the number of accidents is 29 (14.4 percent) but, for less than 100 hours in type, the number of accidents increases to 123 (61.0 percent). A more detailed review of the data shows that there are 88 accidents (62.9 percent) classified as mismanagement of fuel where the pilots had less than 100 hours in type. Correspondingly, there are 35 accidents (56.5 percent) classified as improper operation of powerplant and powerplant controls where the pilot had less than 100 hours in type. There is an indication of a higher frequency of occurrence where mismanagement of fuel is the cause with pilots having less than 100 hours in type. This substantial jump in the low-time groups is accompanied by a decrease in the high-time groups. Note that on the basis of total piloting time, there are 88 cases with more than 1000 hours but, for time in type, this drops to only 17 cases. Thus, the impressive experience of the pilots involved in the accidents is greatly diminished if only time in type is considered. This could be expected to influence the selection and potential effectiveness of accident countermeasures.

A. Mismanagement of Fuel



B. Misuse of Powerplant and Powerplant Controls

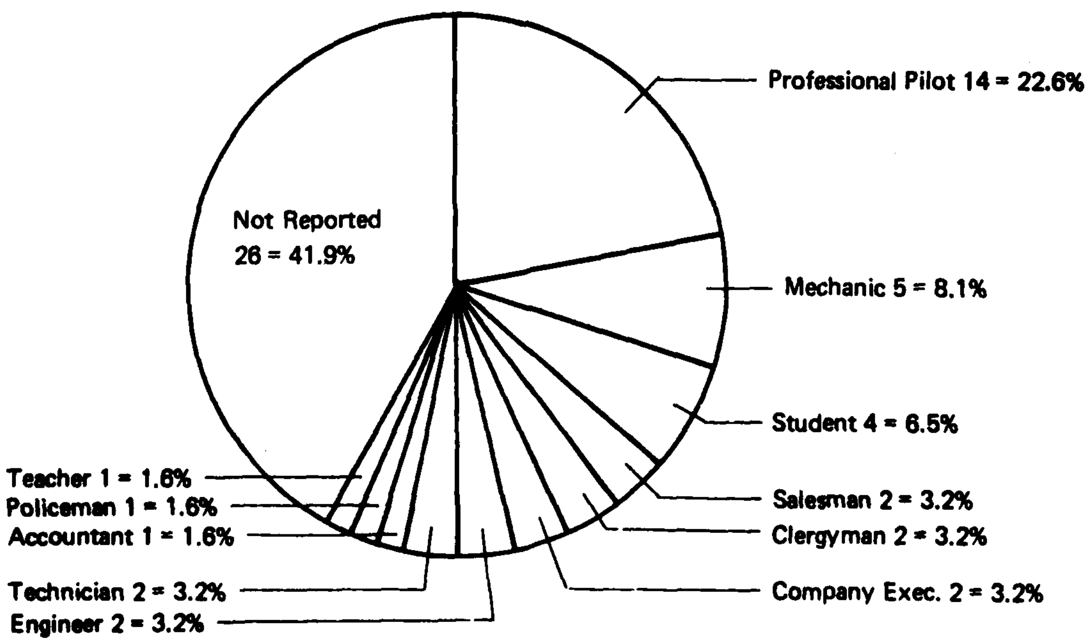


FIGURE 1. DISTRIBUTION OF PILOT OCCUPATION

MISMANAGEMENT OF FUEL

PILOT TOTAL HOURS

CODE	PILOT TOTAL HOURS	FREQUENCY
1.	0-25	10
2.	26-50	3
3.	51-100	7
4.	101-300	28
5.	301-500	14
6.	501-1000	23
7.	1001-3000	26
8.	3001-5000	17
9.	5001-8000	3
10.	8001-10000	1
11.	OVER 10000	8

FREQUENCY (scale 0, 10, 20, 30, 40, 50)

IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS

PILOT TOTAL HOURS

CODE	PILOT TOTAL HOURS	FREQUENCY
1.	0-25	1
2.	26-50	2
3.	51-100	6
4.	101-300	11
5.	301-500	3
6.	501-1000	6
7.	1001-3000	17
8.	3001-5000	6
9.	5001-8000	4
10.	8001-10000	1
11.	OVER 10000	5

FREQUENCY (scale 0, 4, 8, 12, 16, 20)

FIGURE 2. DISTRIBUTION OF PILOT TOTAL HOURS

MISMANAGEMENT OF FUEL

IMPROPER OPERATION POWERPLANT AND POWERPLANT CONTROLS

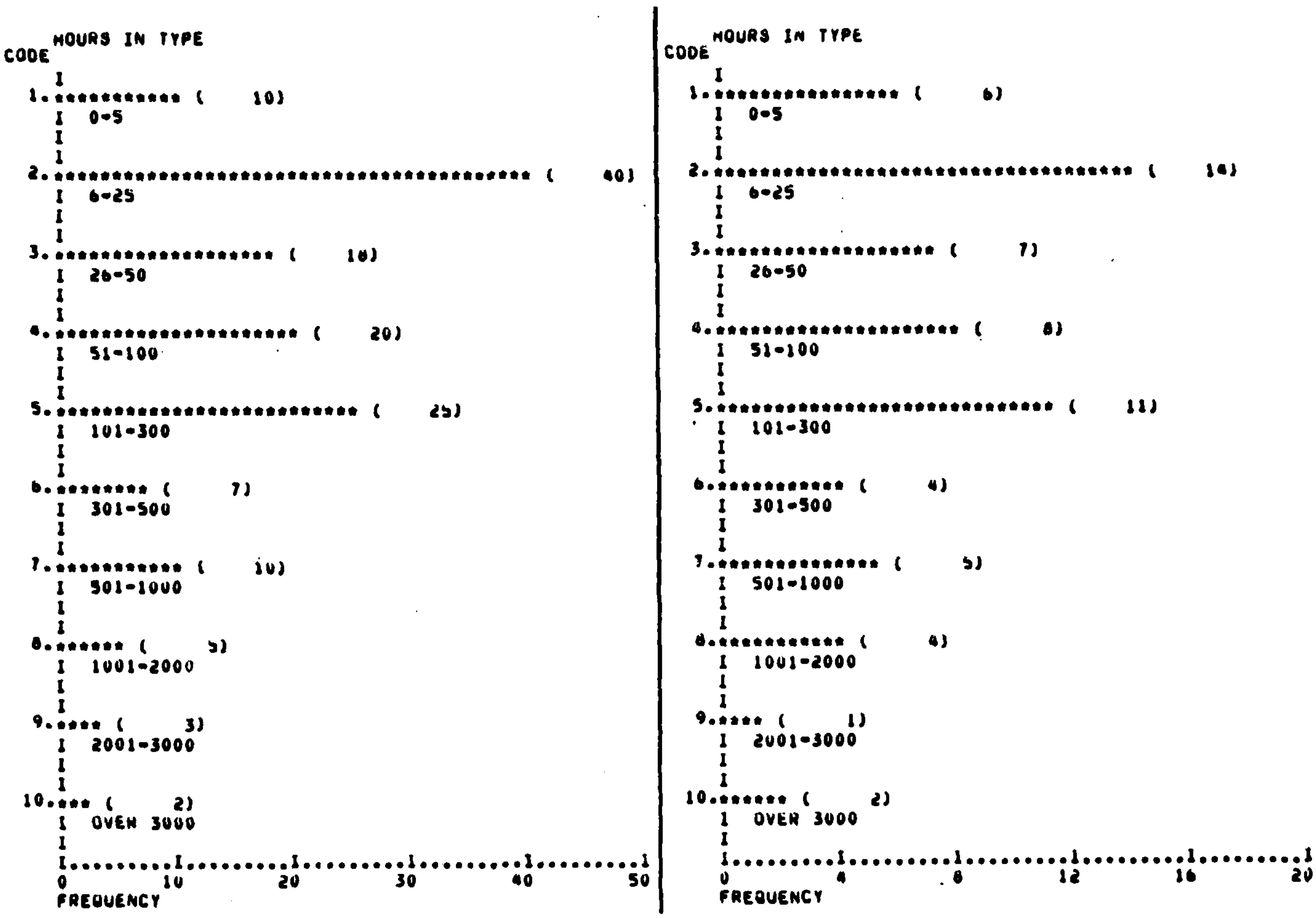


FIGURE 3. DISTRIBUTION OF PILOT FLYING TIME IN AIRCRAFT TYPE

Pilot Ratings. The largest group of pilots involved in the accidents hold single-engine-land ratings, as shown in Figure 4. This group is roughly half the total. All the categories that are instrument rated within the 200 case sample aggregate 35.1 percent. Reviewed separately, mismanagement of fuel accidents indicate that 32.9 percent of the pilots involved held instrument ratings while improper operation of the powerplant and powerplant controls accidents indicate that 40.3 percent of the pilots involved held instrument ratings. The data on pilot ratings, taken together with the prevalence of bad weather during many of the accidents, are useful in assessing the probable effectiveness of tightened pilot restrictions as a countermeasure to the engine failure accidents. It is of additional significance to note that according to the NTSB extracts from pilot logs, 165 pilots (81.7 percent) did not log any actual instrument time, 168 pilots (83.2 percent) did not log any simulated instrument time, and 154 pilots (76.2 percent) did not log any night time. The accuracy of these figures is subject to the accuracy of the NTSB data base.

Pilot Certificate. The main benefit from examining the compiled data on pilot certificate (Figure 5) is a cross-check on the previous figures. The holders of commercial certificates are closely in line with the number of professional pilots in the occupational distribution. However, if the two groups of flight instructors are added, it would appear that the number of professional pilots is in error and too low. The possibility exists that some of the holders of a commercial certificate are presently in non-piloting occupations. However, it should be expected that the commercial certificate and flight instructor groups would be instrument-rated.

Pilot Limitations. A very high proportion (90 percent) of the sample accident pilots required the use of eyeglasses for corrective vision. In several of the fatal accidents where the information was reported by the NTSB investigators, eyeglasses were recovered at the accident scene within luggage but no eyeglasses were recovered on or near the victims. In the majority of cases, however, no mention of eyeglass use was provided by the investigator.

FLIGHT CONDITIONS.

Weather. In the broader reviews and reports on general aviation accidents, the most frequent causal factors for fatal accidents are found to be weather related. The first is "Weather-Low Ceiling" and it is followed by "Pilot-Continued VFR Flight Into Adverse Weather Conditions." The accidents of the selected cases are along the same pattern with these weather conditions:

Visual Flight Rules (VFR) - 89.6 percent
Instrument Flight Rules (IFR) - 10.4 percent

Light Conditions. Both in regard to cockpit tasks and to flight navigation, each involved in some of the accidents, illumination has some bearing on the evolution of the accident. The selected cases have conditions of low light in more than one-fourth of the accidents, as shown in Figure 6, when the non-daylight periods are combined.

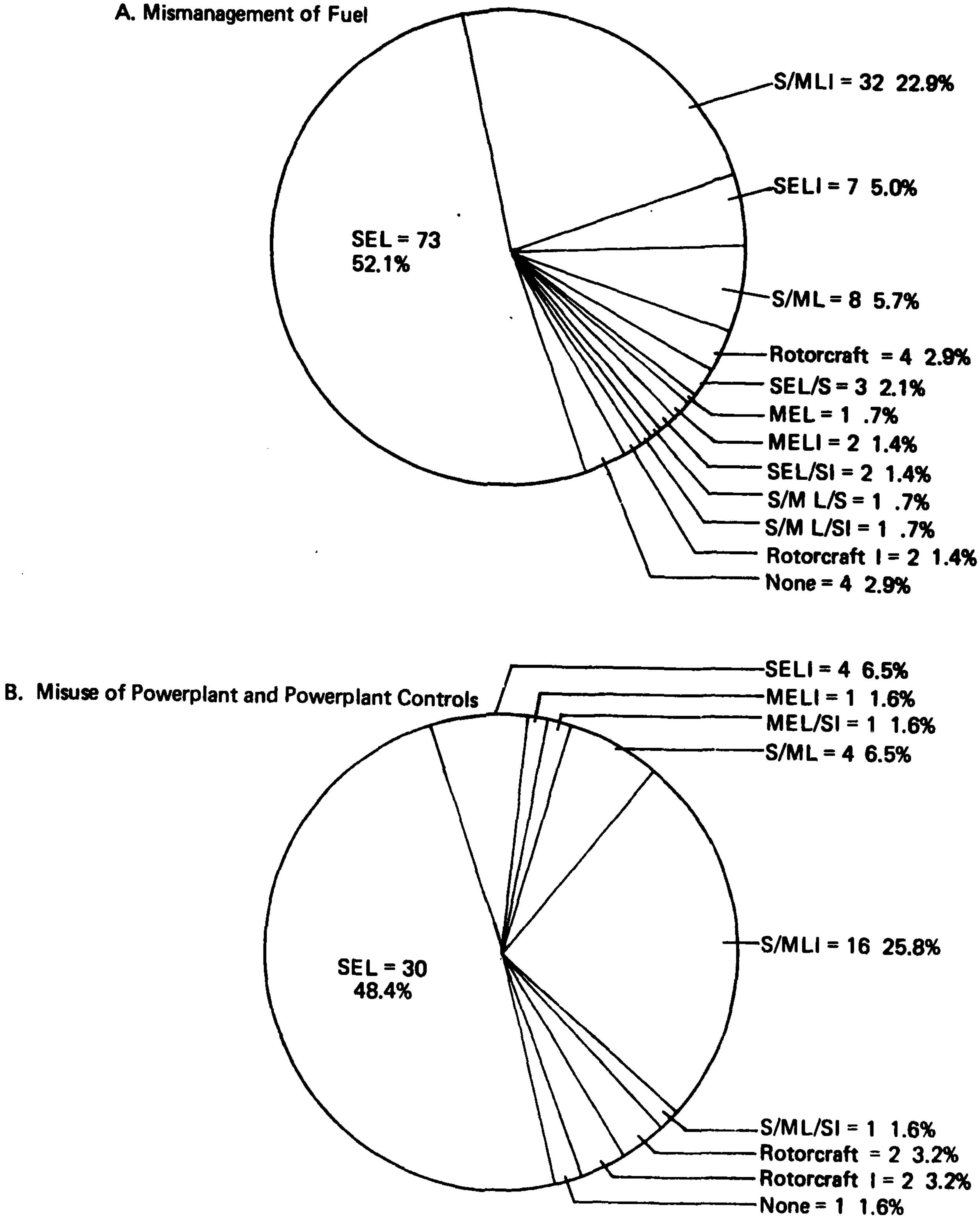
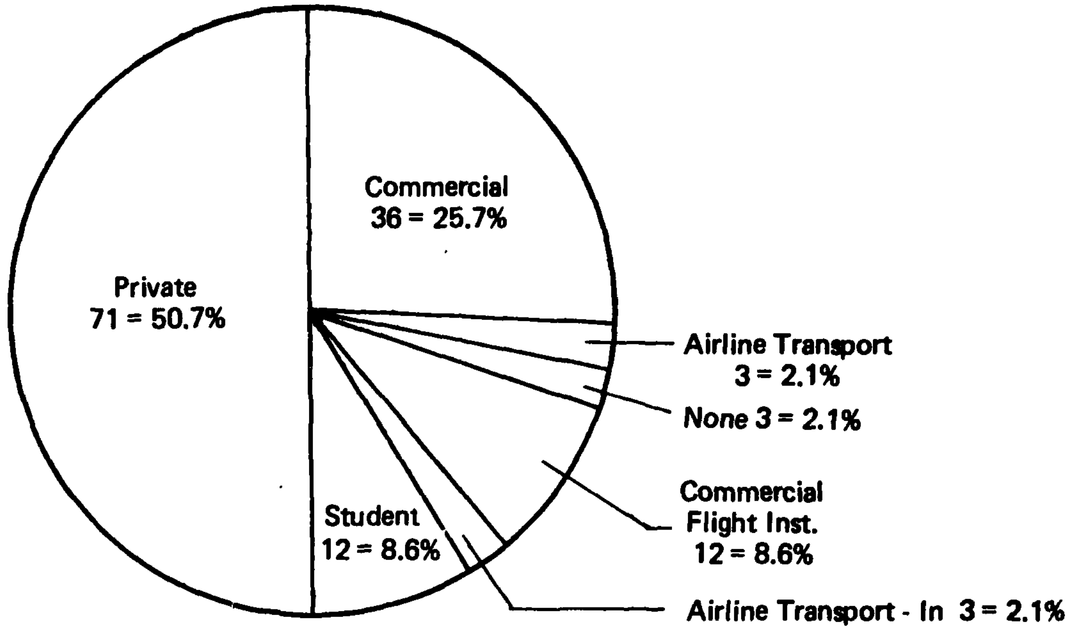


FIGURE 4. PILOT RATINGS

A. Mismanagement of Fuel



B. Misuse of Powerplant and Powerplant Controls

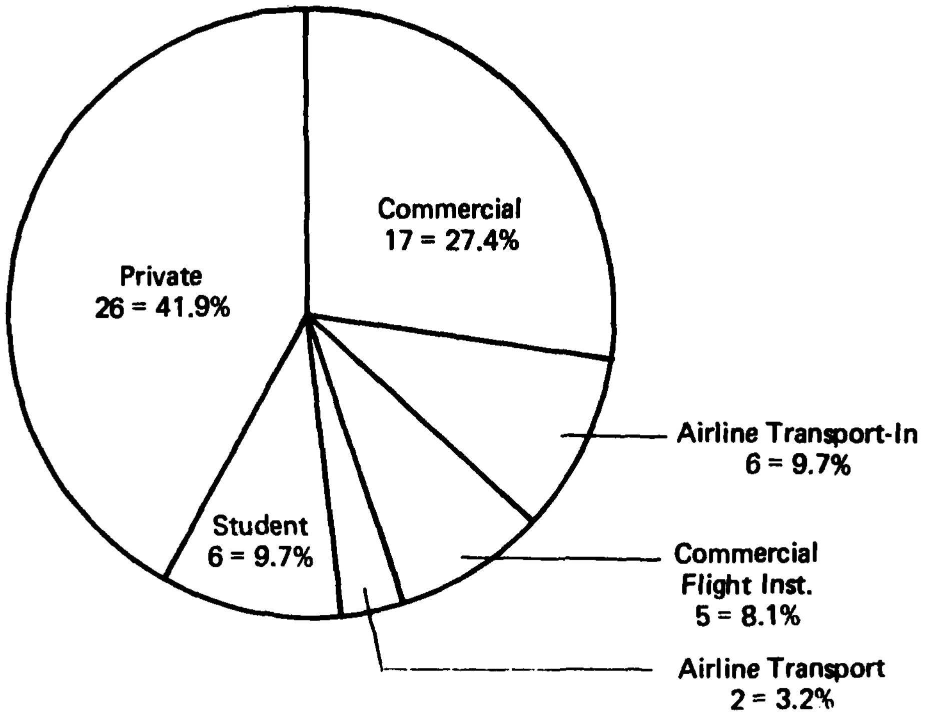
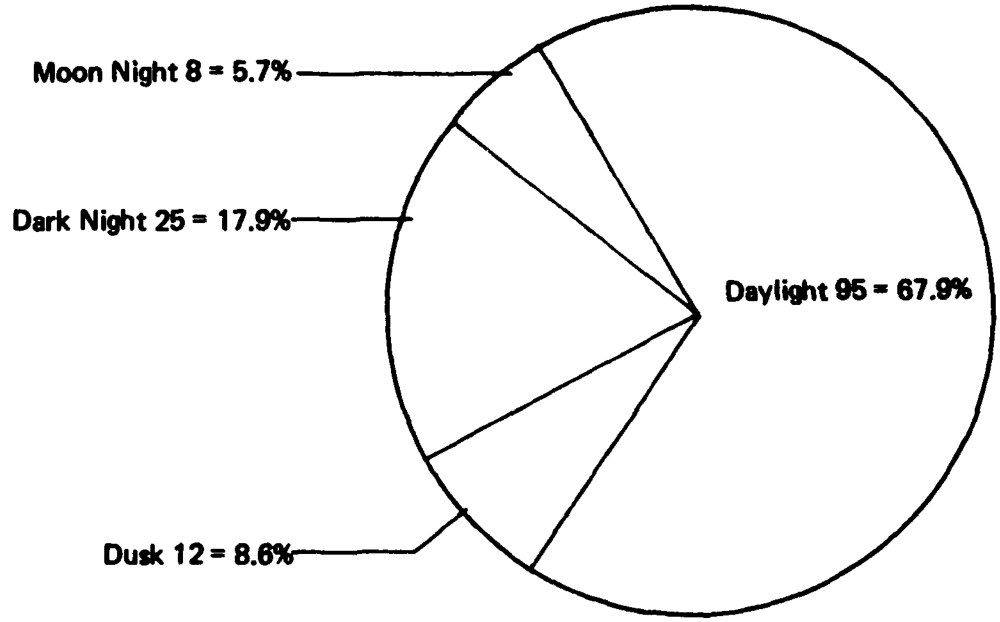


FIGURE 5. DISTRIBUTION OF PILOT CERTIFICATE

A. Mismanagement of Fuel



B. Misuse of Powerplant and Powerplant Controls

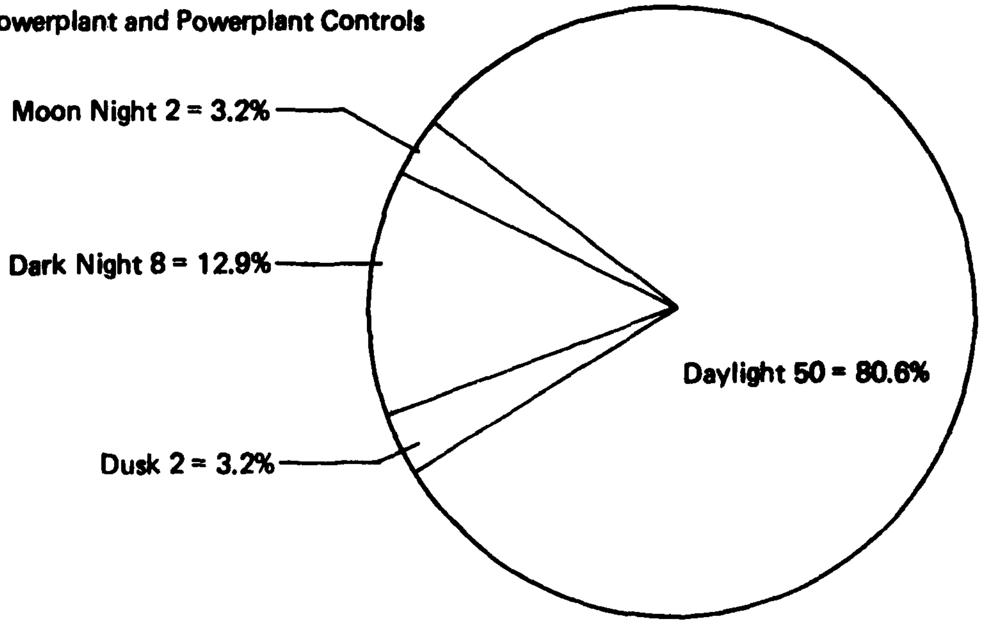


FIGURE 6. LIGHT CONDITIONS

Temperature. The relevance of temperature information is an indicator of potential icing conditions. It would be possible to make a better estimate on icing conditions with a dew point reading along with temperature but many of the accident files do not have this information recorded. Nevertheless, the two blocks of accidents spanning the temperature range of 21-60°F are in the range where carburetor icing may occur. The number of accidents there is 22, or 30 percent of the total where the temperature was recorded.

PHASE OF FLIGHT OPERATIONS. In examining comprehensive accident studies including all accident types over recent years, two patterns emerge. The data for year 1978 are typical (Reference 8) and show that for total accidents the landing phase was most frequent (41.3 percent) and in-flight was second (33.6 percent). However, if fatal accidents only are considered, most of the accidents are in-flight (63.7 percent) and the landing phase group is second (17.5 percent).

It was previously noted that the accidents of the sample data base, where engine failure dominates, have a much higher than average proportion of fatal accidents. The distribution of flight phase for the sample is in Figure 7 where it is apparent that the landing phase contains most of the mismanagement of fuel accidents (81.4 percent), and the in-flight phase contains most of the improper operation of powerplant and powerplant controls accidents (43.5 percent). The distribution of the accidents conforms nearly to the finding for fatal accidents only, although here there are slightly more accidents during takeoff than in landing. In short, the form of the accident distribution over flight phases is about what might be expected for the accident types in the sample.

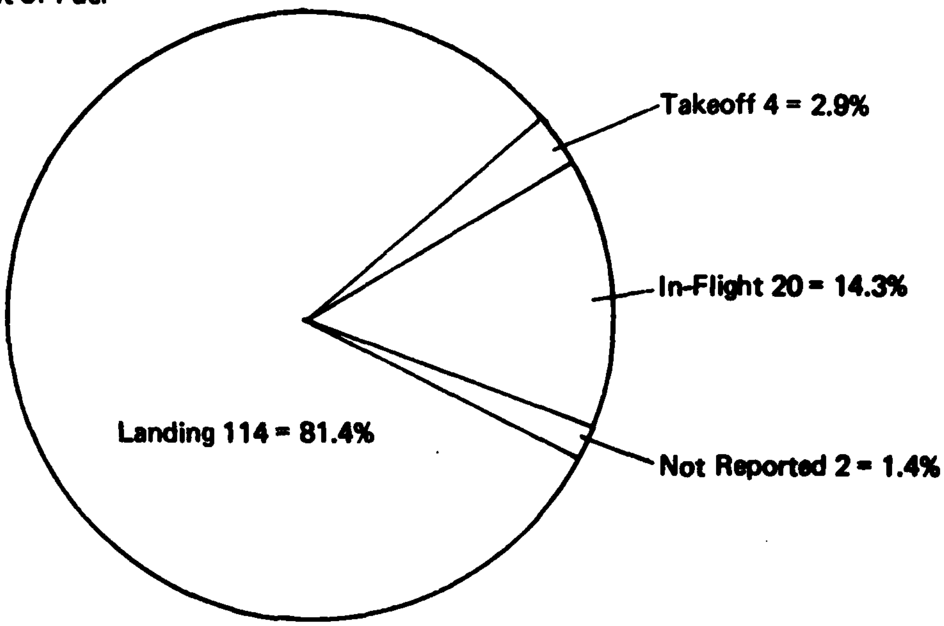
DESCRIPTION OF AIRCRAFT.

Makes and Models. While there is no intention to study the performance of specific makes and models of aircraft as related to the fuel starvation and engine failure problems, it is significant that the sampling process has produced a satisfactory distribution here. Distribution of makes and models in the sampled accidents is shown in Appendix A. It is immediately obvious that the three major manufacturers are well represented in the listing but the smaller companies are also present.

The basis for the satisfactory nature of the distribution lies in comparison with the findings from large-scale accident analyses over a number of years. Typical distribution of total flying hours is in the following proportions (data derived from Reference 2):

Cessna	4.0
Piper	2.6
Beech	1.0

A. Mismanagement of Fuel



B. Misuse of Powerplant and Powerplant Controls

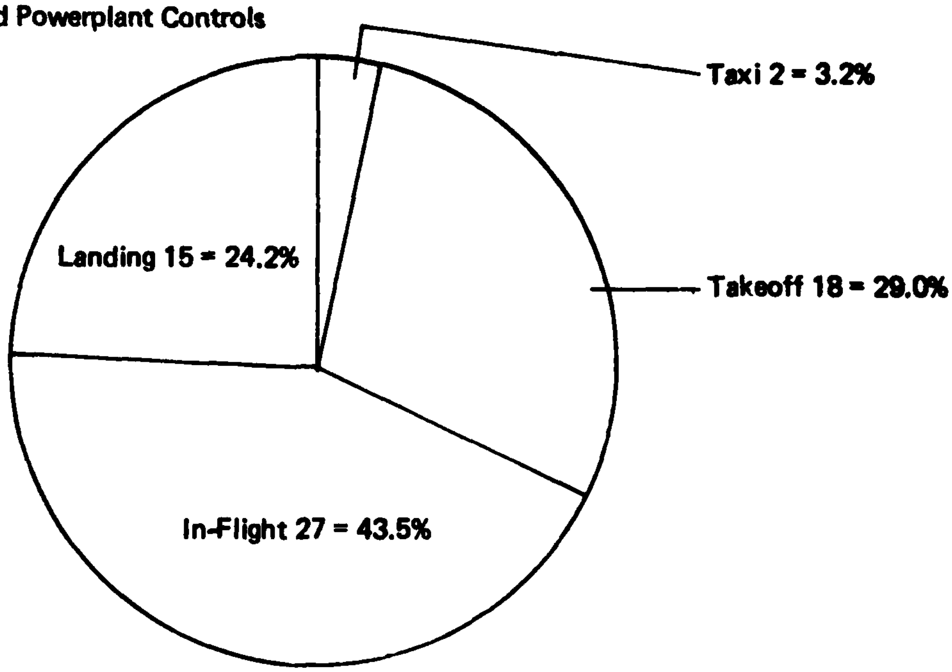


FIGURE 7. DISTRIBUTION OF FLIGHT OPERATION PHASE

However, the proportions of makes and models in the accident cases have not been in these ratios. This has led to classifications of certain aircraft as being high involvement or low involvement, with some being very high or very low. Typically, Cessna models have been rated as low and very low involvement aircraft (see also Reference 3 which covers fuel starvation accidents for three years). Thus, the presence of fewer Cessnas than would be expected solely by consideration of flying hours conforms to existing patterns of accident experience. Appendix A is a tabulation of the manufacturer/model/series for all aircraft in the 200 accident sample.

The number of twin-engine aircraft is also found to be reasonable. The ratio of single-engine to twins is 9.1:1. In the past this ratio has been in the range of 8.5:1 to 9.8:1.

In addition to the three majors, the make/model distribution includes a representative list of the lower production rate manufacturers. There are 30 manufacturers in this group and 61 airplanes. Of the 61, three are helicopters, three are agricultural planes, and ten are amateur built or experimental aircraft.

DESCRIPTION OF AIRCRAFT FUEL SYSTEMS. The overall function of the fuel system is to enable effective propulsion by delivery of an adequate and controlled quantity of fuel to the engines. Lower level functional elements are primarily: fuel storage, routing of fuel flow, rate control of fuel flow, shut-off of fuel flow, mixture control, and display of fuel status information to the pilot. There is some overlap between these elements and powerplant controls, for example the throttle and mixture controls appear on fuel system schematics but are obviously primary powerplant controls.

Gravity-feed Systems. Several categories of fuel system arrangement may be observed on various makes and models of general aviation aircraft. The extreme of simplicity is the gravity-feed system, containing no powered elements and limited to high-wing designs. Fuel in two wing tanks can be selectively consumed by operating a selector valve, some details of which are covered below. Such an arrangement will probably route the fuel lines independently to the selector for flow path switching, and may include a position for drawing on both tanks concurrently. A variation on this arrangement is the joining of the two lines prior to their reaching the selector valve thereby removing the freedom to select a tank at will and resulting in only one ON position at the selector which draws on both tanks.

Other vital components are included in the fuel systems. One or more strainers will trap solid contamination before it reaches the carburetor. These may be located near the selector valve, in the engine compartment, or may be within fuel tanks near the outlet. Drains are provided to assure the removal of water or sediment from fuel. Their location is generally on fuel tank bottoms, but strainers and selector valves may also include provision for draining. Fuel tanks will include provision for venting to assure that flow of fuel is not inhibited by a vacuum condition in the tanks.

Pumped-pressure Systems. By incorporation of power fuel pumps in the system, the limitations of the gravity-feed system are overcome. Pumped-pressure systems are necessary due to the widespread acceptance of low wing aircraft. Additional advantages are gained in that fuel flow can be more assured under some critical operating conditions. For example, when switching tanks, there is less chance of an interruption to fuel flow with one or two pumps running. Also, during rough engine performance, it is possible to increase fuel flow by means of an auxiliary fuel pump. The auxiliary pump is normally on for takeoff, landing, in-flight engine restart, and starting a cold engine.

The typical pumped-pressure system contains both an engine-driven main fuel pump and an electrically powered auxiliary pump. The prevailing arrangement for the pumps is in series, with bypass channels in the pumps allowing normal flow with either pump functioning. An electric switch on the instrument panel activates the auxiliary pump.

Fuel Injection Systems. This is another category of general aviation fuel systems. There are no significant changes in piloting procedures as compared to the pumped-pressure systems but there are material differences in the equipment items. One main characteristic of fuel injection systems is their relative freedom from engine-related icing problems. Thus, there is no provision for carburetor heat; an alternate air source is, however, usually included. Return flow from the fuel pump or regulator is normal as the pump delivers fuel at a rather high pressure and in the regulation process the excess is bypassed. Generally, the airplane models equipped with fuel injection include as standard equipment some items which are optional or not available on simpler models. One such item is the controllable pitch propeller. Another is the long range fuel tank or auxiliary tank. There will probably be both fuel pressure and flow gauges since pressure, as measured just downstream of the pump, is not indicative of fuel flow to the engine because of the return flow.

Twin Engine Aircraft Systems. Much greater complexity is found in twin engine fuel systems, as compared to single-engine airplanes. The engines are independently supplied by their designated tankage. A crossfeed tube is normally in the system to divert fuel from main tanks to an opposite side engine, should this be necessary. A usual interconnect point is near the main tank and the line then passes to the opposite selector valve. Generally, auxiliary tank fuel supply cannot be diverted to the opposite engine and is therefore consumed initially.

FUEL SYSTEM COMPONENTS.

Fuel Selector Valve. In observing the problems of fuel system management, the fuel selector valve is found to be the most involved component. This must be repositioned in flight to accomplish several functions. Tank selection will switch from one side to the other to maintain lateral balance of the fuel load. Additionally, when auxiliary tanks are not connected to mains, which is the usual case, they can be drawn upon by selector settings. In the event of a flight emergency involving engine performance, the prescribed procedures include switching to the fullest tank or to the opposite side tank. For most twin engine aircraft, crossfeed is accomplished by a selector setting.

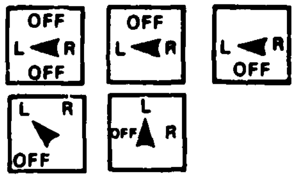
Of particular concern in this investigation are the patterns of the positions on the selectors and the location of the selector in the cockpit. In both regards, great variability is found in the designs of general aviation and, specifically, the aircraft in the sample of engine related accidents. As part of the ground work for estimating the probable effectiveness of accident countermeasures of the standardization type, it is in order to examine this variability.

A listing is given below for fuel system flow arrangements along with the corresponding selector patterns. Note that several selector patterns appear for essentially similar flow arrangements:

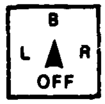
Flow of Fuel — Selector Pattern

1. Main tanks interconnected on a single main tank, two position selector.

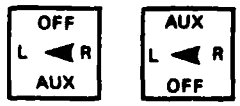
2. Main tanks alternately available, two tanks only, selector with three or four positions depending on OFF positioning.



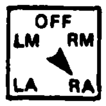
3. Main tanks alternately available, also main tanks may concurrently feed thus adding a BOTH position.



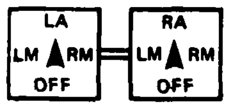
4. Auxiliary tank added, while retaining two main tanks, auxiliary tank may be single unit or left and right units interconnected.



5. Auxiliary tanks are available separately along with the two mains, resulting in five selector positions.



6. Twin engine aircraft with two selectors, main tanks available to either selector (crossfeed option), auxiliary tanks available only to on-side engine, opposite main tank position may be designated CROSSFEED.



Several safety features appear in the more recent designs of selector valves, being mandatory or preferred, as summarized in Reference 10. Switching from one tank to another avoids passing through an OFF position. Detents provide the pilot with a feel that the selected position is actually engaged. Operating handles incorporate a pointer on the long end. A safety button may be on the handle to be depressed for entry to the OFF position. Also, selector valves are placarded with the useable fuel capacity for each tank.

The problem of locating the selector valve in the cockpit is related to the routing of fuel lines since the lines must connect up to the valve. The valve handle is either directly on the valve or somewhat remotely located so as to improve pilot access to the handle. However, the only explanation for the majority of the valve locations is that the fuel line routing constraint is overriding and that remote handles are not used or only slightly displaced from the valve. Typical locations of the selector in sample accident cases are:

1. Left cabin wall panel forward of seat.
2. Left cabin wall panel over door and abreast of seat.
3. Center of floor, between seats.
4. On a central panel below throttle quadrant.
5. On the control pedestal, central.
6. On the instrument panel, left side.

Fuel Gauges. The aircraft of the accident sample show great variation in the presentation of fuel quantity status to the pilot. In many designs, there is a quantity gauge for each tank but, in other cases, switches must be operated where a single gauge serves more than one tank. The consequence is that, in an emergency requiring immediate selection of the fullest tank, there may be a serious delay while the determination is made of quantity status. A tabulation here shows the main variations, including twin engine aircraft:

	Tankage		Gauges
1.	Two main tanks - interconnected	-	Two gauges
2.	Two main tanks - independent	-	Two gauges
3.	Two main tanks - independent	-	One gauge - switch to read each tank
4.	Two main tanks - plus two auxiliary tanks	-	Two gauges, read main-switch to read auxiliary
5.	Two main tanks - plus two auxiliary tanks	-	One gauge-switch to read mains and auxiliaries
6.	Two main tanks - plus two auxiliary tanks	-	One gauge-press knob on selector to read any tank in use

Location of the fuel quantity gauges is another element in the presentation of quantity status. Several of the sample aircraft designs provide an integrated fuel management panel so that quantities can be observed and selector switching performed without any refocusing by the pilot. However, the general situation is that fuel gauges are collected together with engine monitoring gauges at various positions on the instrument panel and there is no association of indicator with control actuator.

Fuel Pressure and Flow Gauges. These gauges assist the pilot in monitoring engine performance. Anomalies in fuel pressure will frequently indicate that some immediate action is required to head off the interruption of engine power, or that a resetting is necessary for best mixture. For carburetor-equipped engines, the pump delivery pressure is proportional to fuel flow rate and only one gauge is necessary. For fuel injected engines, both pressure and flow gauges are usual with the former useful in fuel pump monitoring. The flow gauge in this case would be downstream of the bypass point in regulation of flow to the engine and thus serve as an aid in mixture setting. Pressure and flow gauge have a wide variation in location, comparable to the quantity gauges, and very little interrelation of gauge with control.

POWERPLANT CONTROLS. This group of controls enables the pilot to adjust engine output, and fuel consumption to a degree and includes throttle, mixture richness, propeller setting (if a controllable-pitch propeller is provided), and carburetor heating (except fuel injected engines). In general, there is more standardization of these controls and their associated instruments than was observed for the fuel system components.

Throttle. Two forms are taken by throttle actuators, even though the function of controlling air flow to the engine is the same in either case. For smaller airplanes, the throttle design is a push-pull rod, with a round knob-type handle, usually of a larger diameter than those of nearby controls. The alternative is a lever-type actuator with an elongated cylindrical form for the handle. For twins, the levers are closely spaced and the handles are trimmed in length. Friction locks are generally provided to maintain a selected throttle position, usually with adjustability in friction force. Operation is conventionally forward to open and aft to close.

Location of the throttle is fairly uniform over the range of makes and models. A throttle quadrant is centrally positioned just below the instruments. For the push rod type, the location may be directly on the instrument panel but still in the center and low. The general rule is the throttle to the left of mixture control.

Mixture Control. This control compensates for the reduced density of the atmosphere at altitude and can be used to increase power in special flight situations. The usual location is to the right of the throttle. Handle designs generally include a distinctive pattern around the periphery for rapid touch recognition, and additionally will be smaller than the throttle. Friction locks are included here also.

Propeller Control. When included in propulsion design, controllable pitch propellers produce a set constant engine speed under varying engine load conditions. The control handle or knob for setting the speed is in the vicinity of the other engine controls but is distinguishable by its handle shape or rim pattern. Propeller controls may be left or right of the throttle and may be between the throttle and mixture control.

Carburetor Heat Control. Preheating of engine intake air can melt incoming ice or prevent ice buildup following mixture formation in the carburetor. The control enables the pilot to use full or partial heat. However, flight manuals warn that an application of heat should be intense enough to clear mixture passages thoroughly and that partial heating can even worsen conditions. Also, manuals leave much to the judgment of pilots with such instructions as the avoidance of carburetor heat on takeoff or landing unless such heat is required. There is very little assistance in the way of guidelines for the decision on when conditions require the application of heat.

The location of the carburetor heat control is somewhat varied but a position to the left of the throttle is more common than others. No particular distinguishing form is in widespread use for the knob of this control.

Engine Instruments. A grouping of the several vital engine instruments assists the pilot in monitoring engine performance. Location for the group is frequently on the left side but right side and center locations are not unusual. The manifold pressure gauge is made conspicuous by its larger size and may be in its preferred location directly above the throttle even at the penalty of scattering engine-related instruments. A tachometer is also prominent in the group. Monitoring of oil pressure and engine heat is generally provided, and the latter may include multiple thermal pickups. Some designs contain a detector of potential icing conditions. Warning lights may be provided as signals of extreme conditions.

ASSIGNMENT OF ACCIDENT COUNTERMEASURES.

With the accidents of the representative sample available for detailed analysis, the next major step is the assignment of accident countermeasures. Obviously this will be a hypothetical situation. It is necessary to assess the probability that the accident would not have occurred if certain features of the cockpit would have been altered. The alternate countermeasure of stricter pilot ratings contains equally hypothetical considerations in assessing whether the accident could have been prevented. Emphasis in this area must be on formulating an objective procedure--one that would produce a comparable outcome regardless of the analysts doing the assessment.

STANDARDIZATION GUIDELINES. The work performed at the National Aviation Facilities Experimental Center (presently the FAA Technical Center) and published in 1978 (Reference 10) was found to be the most authoritative and comprehensive work on the subject of cockpit standardization. The work included intensive queries of pilots, analysis of accident reports, and consideration of the practicality of standardizing the cockpit design features. Contributions from GAMA and the Aircraft Owners and Pilots Association (AOPA) are included. A broad view of the nature of standardization is apparent in the report since coverage includes such matters as:

1. Owner manuals and the need for more detailed information therein.
2. The use of placards.
3. Imposition of quality standards, as for example, more accurate and reliable fuel quantity gauges.
4. Pilot workload simplification.
5. Illumination improvements.

For purposes of this section, all the potential improvements in standardization are regarded as countermeasures available for preventing an accident. Thus, the material in the report is taken as a set of guidelines on standardization regardless of whether any item is a vague proposal, a firm recommendation, or a Federal Aviation Regulation whose benefits have yet to be realized. The main areas where standardization could be applied are noted below (where it can be observed that there is a relationship to the design variations recorded in the previous section describing the aircraft of the accident sample):

1. Coordination of Instruments and Controls
   a. Fuel quantity gauges/selector valves.
   b. Manifold pressure gauge/throttle.
   c. Temperature gauge/carburetor heat control.
   d. Fuel rate gauge/mixture control.
   e. Tachometer/propeller control.

2. Sequencing and Grouping of Controls
   a. Carburetor heat/throttle/mixture.
   b. Propeller control.
   c. Supercharger control.
   d. Fuel system selector valve.

3. Tactile Coding
   a. Edge patterns on powerplant controls.
   b. Handle shape on selector valves.
   c. Control motion of actuators/handles.

4. Visual and Sound Warnings
   a. Low-fuel-level lights.
   b. Carburetor icing alarm.
   c. Color coding on powerplant controls.
   d. Red position mark on selector.

5. Interlocks and Two-step Control
   a. Mixture control push button.
   b. Friction locks on powerplant controls.

6. Accessibility of Controls
   a. Fuel selector valve positioning.

7. Visibility of Instruments and Controls
   a. Size of fuel quantity gauge.
   b. Instrument panel illumination.
   c. Selector valve visibility.

8. Manuals, Placards, and Instructions
   a. Preflight placard.
   b. Emergency procedures placards.
   c. Tank switching procedure instruction.
   d. Carburetor heating procedures instruction.
   e. Engine restart procedure instruction.

9. Quality Standards
   a. Fuel quantity gauge accuracy.

Case Study Approach. Of the 200 accident sample, 190 cases have been reviewed in detail at least three times and in many instances several times more. The reviews consisted of a detailed analysis of each case with an attempt to categorize each case by specific countermeasure assignment:

1. Preventable by Standardization.
2. Preventable by Pilot Restriction.
3. Preventable by Both Standardization and Pilot Restrictions.
4. Not preventable by either countermeasure.

As a means of recording the initial assignment of countermeasures for each case, a matrix of primary cause/factors and contributing cause/factors was developed. Tables 7 and 8 are copies of these matrices. As in all cause/result relationships, there are chains of events which unfold leading to the accident. An attempt to record these relationships through the utilization of the matrices was made. Of primary concern with the mismanagement of fuel cases was distinguishing between those accidents identified as fuel exhaustion from those identified as fuel starvation. Although fuel starvation was the primary concern with regard to cockpit standardization countermeasures, there was an attempt to identify and tabulate all contributing cause/factors including those recommended as inadequate preflight preparation. The primary concern with regard to powerplant controls was whether the controls were available and not used or whether they were used but improperly.

The summaries of the tabulations of these initial countermeasure assignment sheets are provided in Table 9, mismanagement of fuel, and Table 10, improper operation of powerplant and powerplant controls. Those accidents receiving a (1), (2), or (3) countermeasure assignment were then reviewed again with regard to countermeasure effectiveness rating schemes described in the following sections. These schemes represented the last test to determine whether or not an accident was preventable or was not preventable.

COUNTERMEASURE EFFECTIVENESS RATING. This study commands that a prediction be made on whether the outcome of the accidents would have been altered if cockpit standardization prevailed at a more nearly optimum level. The available standardization measures have been outlined generically. It is now in order to consider the kind of pilot errors involved in the accidents and to rate effectiveness of the countermeasures in combating the errors.

Pilot Error Breakdown. A convenient guide to a breakdown of pilot error categories is available in an FAA sponsored study (Reference 11). The human error fault tree from the report is reproduced here as Figure 8. The right hand side of the fault tree is of concern in formulating a compendium of pilot errors in the accidents. All of the three primary categories of error -- cognition errors, decision errors, and execution errors - are to be countered by standardization. There are additional branches to the overall fault tree covering mechanical and environmental errors. Obviously some of the accidents contain multiple causes including elements from these two other branches. Standardization could not be expected to counter those errors.

TABLE 7. INITIAL COUNTERMEASURE ASSIGNMENT SHEETS
Mismanagement of Fuel

CONTRIBUTING/FACTOR	FUEL EXHAUSTION	FUEL STARVATION	TOTAL
1. Fuel system which requires tank switching in order to manage the fuel supply properly.			
2. Incorrect positioning of fuel selector valve which resulted in fuel starvation.			
3. Improper use of powerplant controls.			
4. Instructional techniques for emergency simulation by deliberate fuel starvation at low altitude.			
5. Lack of knowledge or concern for good fuel management procedures and techniques.			
6. Improper in-flight decisions and planning.			
7. Continued VFR flight into IFR conditions while not instrument rated or current.			
8. Inadequate preflight.			
9. Lack of familiarity with aircraft.			
10. Diverted attention from operation of aircraft.			
11. Inadequate supervision of flight.			
12. Spontaneous, improper action.			

TABLE 8. INITIAL COUNTERMEASURE ASSIGNMENT SHEETS
Improper Operation of Powerplant and Powerplant Controls

CONTRIBUTING/FACTOR	IMPROPER OPERATION OF EQUIPMENT	FAILED TO USE AVAILABLE EQUIPMENT	TOTAL
1. Selected wrong control.			
2. Failed or delayed execution of decision.			
3. Difficult powerplant operational procedures which may contribute to pilot error.			
4. Improper operational decision.			
5. Lack of knowledge or concern for adequate use of powerplant controls.			
6. Continued VFR into IFR conditions while not instrument rated or current.			
7. Diverted attention from operation of the aircraft.			
8. Improper in-flight decisions or planning.			
9. Inadequate supervision of flight.			
10. Lack of familiarity with aircraft.			
11. Spontaneous, improper action.			

TABLE 9. TABULATION OF MISMANAGEMENT OF FUEL COUNTERMEASURES

CONTRIBUTING/FACTOR	FUEL EXHAUSTION	FUEL STARVATION	TOTAL
1. Fuel system which requires tank switching in order to manage the fuel supply properly.	59	47	106
2. Incorrect positioning of fuel selector valve which resulted in fuel starvation.	4	32	36
3. Improper use of powerplant controls.	9	4	13
4. Instructional techniques for emergency simulation by deliberate fuel starvation at low altitude.	0	0	0
5. Lack of knowledge or concern for good fuel management procedures and techniques.	45	29	74
6. Improper in-flight decisions and planning.	52	10	62
7. Continued VFR flight into IFR conditions while not instrument rated or current.	5	0	5
8. Inadequate preflight.	51	13	64
9. Lack of familiarity with aircraft.	14	16	30
10. Diverted attention from operation of aircraft.	0	2	2
11. Inadequate supervision of flight.	2	0	2
12. Spontaneous, improper action.	0	1	1
Number of Cases	82	49	131

TABLE 10. TABULATION OF IMPROPER OPERATION OF POWERPLANT AND POWERPLANT CONTROLS COUNTERMEASURES

CONTRIBUTING/FACTOR	IMPROPER OPERATION OF EQUIPMENT	FAILED TO USE AVAILABLE EQUIPMENT	TOTAL
1. Selected wrong control.	4	0	4
2. Failed or delayed execution of decision.	15	6	21
3. Difficult powerplant operational procedures which may contribute to pilot error.	7	0	7
4. Improper operational decision.	20	4	24
5. Lack of knowledge or concern for adequate use of powerplant controls.	27	6	33
6. Continued VFR into IFR conditions while not instrument rated or current.	0	1	1
7. Diverted attention from operation of the aircraft.	0	1	1
8. Improper inflight decisions or planning.	6	4	10
9. Inadequate supervision of flight.	0	1	1
10. Lack of familiarity with aircraft.	14	1	15
11. Spontaneous, improper action.			
12. Other exceptional condition.	2	0	2
Number of Cases	47	12	59

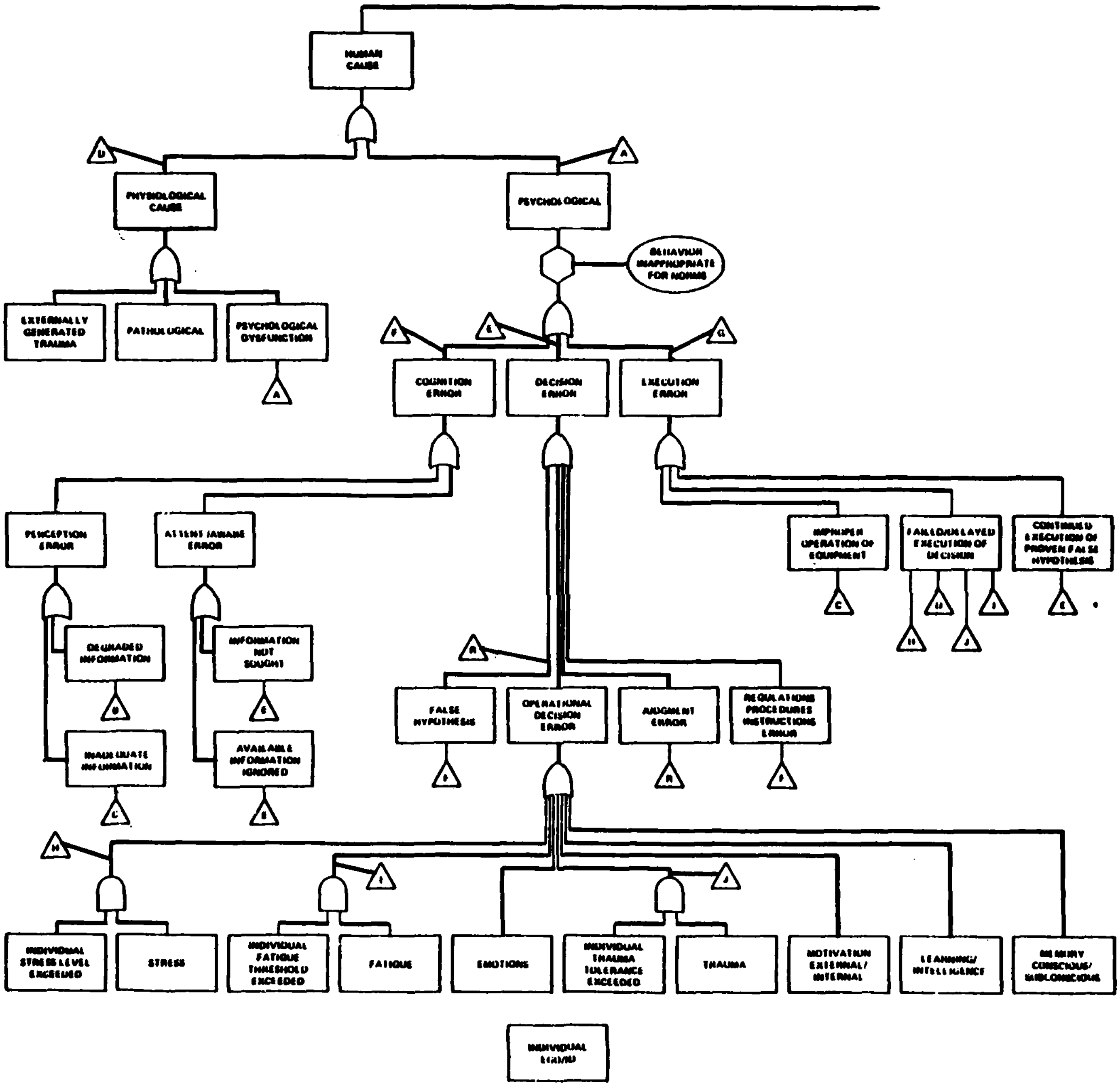


FIGURE 8. HUMAN ERROR FAULT TREE DIAGRAM
(Reproduced from Evaluation of Safety Programs with Respect to the Causes of Air Carrier Accidents)

The Countermeasure Rating Scheme. An overlay of the pilot error categories and standardization elements leads to the rating scheme. In effect, this device avoids the gross estimate that standardization or a more nearly optimized cockpit configuration would/would not have prevented a particular accident from occurring. By forcing the evaluator to consider the lower level elements of the pilot error in combination with the lower level elements of standardization, the decision process is rationalized. Thus, the result is moved from the subjective in the direction of the objective. Certainly some degree of uncertainty remains. However, the reproducibility of the rating results is markedly improved.

The standardization countermeasure rating chart is shown in Table 11. Individual items carry a rating value of one or two points depending on the directness of the standardization measure. For example, if a pilot actuated the mixture control push rod when his intention was to apply carburetor heat, and either of the control locations is inappropriate according to the standardization guidelines, then this would be a high counterforce influence and worth the higher value of two points. On the other hand, if some particular warning is not explicitly stated in the manual or on a cockpit placard, the influence is less direct since it might have been ignored in any case so the countermeasure is worth only one point. The total number of points that might be accumulated is undetermined due to the possibility that more than one instrument or control may be affected by a single rating item.

The necessary number of rating points for a decision that the accident might have been prevented is another hypothetical issue. A value of six has been selected. It is clearly recognized that uncertainty exists here. A case can be conjectured that in selected accidents a single change in cockpit arrangement might have been crucial in prevention. Conversely, there is also some probability that the pilot error, or a similar one, might have been committed no matter to what degree the cockpit design were optimized. The selected value is intended to provide some confidence that there were multiple opportunities, which is usually the case, to prevent the accident and that the standardization effort extended to all or most of them.

THE PILOT RESTRICTION COUNTERMEASURE. There is an alternative to cockpit standardization as a step toward improved matching of the pilot and the airplane, in the form of putting restrictions on the pilot. This kind of measure turns out to be as complex as a determination of the optimum cockpit arrangement. Comprehensive data for comparing accident pilots with the total population of pilots are not available. Several attributes of pilot flying experience could contribute to the safe handling of an emergency, or even a suppression of the incipient emergency.

TABLE 11. STANDARDIZATION COUNTERMEASURE RATING CHART

PILOT ERROR AND COUNTERMEASURE ELEMENTS	RATING PTS ACTUAL *
1. Perception Errors	
a. Information inadequate	
Indicator/gauge not accurate	2
Visibility of gauge is poor	2
Indicator/gauge requires switching	2
b. Pilot not aware of situation	
Gauge not optimally positioned	2
No warnings available	2
Instruction manuals lack warnings	1
2. Decision Errors	
a. Pilot formed false hypothesis	
Interpretation of information difficult	1
Instruction manuals ambiguous	1
b. Operational decision incorrect	
Workload affected by cockpit configuration	1
Analysis time affected	1
Decision-aid checklist unavailable	1
Instructions, procedures inadequate	1
3. Execution Errors	
a. Improper operation of equipment	
Selected incorrect actuator	2
Mispositioned actuator	2
Positioned actuator to unintended setting	2
Visibility of controls inadequate	2
b. Failed/delayed execution of decision	
Control in difficult position	2
Control operation is complicated	2
c. Continued execution of false hypothesis	
Instruments/controls uncoordinated	2
Placards, instructions not available	1
Total Rating	

* Actual points which total 6 or better indicate preventable by standardization.

Total Flight Time. In presenting the characteristics of the accident data base, the total flight time for pilots is shown to vary over an extremely broad range. The obviously experienced group with 1000 to 3000 hours accounts for 15 percent of the accidents. This group is more numerous than those in the two lower ranges. A better comparison could be done by compensating for exposure, as measured by annual flying hours, but the data are not readily available. In any case the comparison still would not be strictly valid since the more experienced pilots may allow themselves to enter higher risk situations than would the low-time pilots. In short, there is no well defined demarcation line based on total flying time to separate a group as being more accident-prone. Total flight time may be useful when used in conjunction with other requirements. In the composite rating, two thresholds are established. Above 1,000 hours, there is the fully seasoned group, and below 300 hours, there are novices and those progressing to total maturity.

Type of Certificate. A requirement based on type of certificate is equally difficult to formulate. The accident data base shows that pilots with commercial or higher rated certificates were involved in about 40 percent of the accidents. Flight instructors and airline transport pilots, the highest ratings, are also included in the accident pilot group in significant numbers. Nevertheless, a commercial or higher certificate is used in the composite rating as an indicator of piloting skill.

Hours in Type. This particular quality of piloting experience would be expected to influence the familiarity of a pilot with a particular cockpit arrangement and his ability to cope with emergency situations. For the accident group, the range of values is 0 to over 3000 hours. For those pilots involved in accidents of mismanagement of fuel, 73.6 percent have between 6 and 300 hours. The range recording the highest number of accidents is 6 to 25 hours (40 accidents). For those pilots involved in accidents of improper operation of powerplant and powerplant controls, 64.5 percent have between 6 and 300 hours. The range recording the highest number of accidents is 6 to 25 hours (14 accidents). Presumably pilots with less than some specified level of time in type aircraft would undergo an appropriate checkout before being allowed to rent or lease such aircraft. With a 100-hour time-in-type requirement, many of the accidents would still have occurred. However, this may be a practical limit for this kind of experience and, if used in a composite requirement, may serve the purpose of rating familiarity along with overall pilot experience and skills.

Another aspect of hours in type is the proportion of total experience which it represents. Assume for example that two pilots each have 100 hours in type but that their totals are 300 and 3,000 hours. It can be argued that in the first case the time in type experience is more significant to the pilot and would aid his reactions to flight problems. In the case of the second, more experienced pilot, the time in type would not necessarily make his reactions more automatic when submerged in a large body of experience in other aircraft having different cockpit arrangements. Thus, the fraction of total experience represented by the time in type has some significance along with the other attributes of experience and is included as a rating element. The threshold is taken at 50 percent of total time in type.

Recency of Experience. If the pilot has had recent flight time there is some assurance that his recall of at least basic procedures will be satisfactory. This will be an asset in the event of an emergency by enabling the pilot to make best use of the limited time for decision and thus keeping the stress level as low as possible. Recency of flight experience does not assure that the pilot will be competent in emergency procedures, but like the other attributes of pilot qualification, can add to a composite requirement. If the pilot has had at least 25 hours in type within the 90 days preceding the flight, it is rated as an asset.

Instrument Time. Of the pilots in the accident sample, 33 percent are instrument rated. Of those not qualified, a significant number encountered weather conditions where visual flight became impossible. This contributed to accidents which might have been prevented if an IFR capability had been present. However, there is no assurance that weather-related general aviation accidents can be positively prevented even with an instrument rating qualification since data show that nearly half the pilots in a sizeable accident sample (Reference 12) were instrument rated. Some further data do show a benefit of instrument time, as the number of accident pilots with high instrument time tends to decrease as their instrument hours increase. Recalling the data base characteristics where only 11 percent of the accidents were under IFR weather conditions, the role of an instrument requirement in a total accident reduction would not be dominant. Nevertheless, instrument qualification is an asset and is included in the rating scheme.

A Composite Pilot Restriction Rating. Given the uncertainties in setting threshold values for pilot qualification elements, the approach taken has been the formulation of a composite rating. All the ratings discussed above are included as well as the additional factor of whether the pilot is the owner of the aircraft. It is postulated that an owner-pilot will, through repeated maintenance and checking, acquire an additional degree of familiarity with the aircraft. The specific values of time or experience have been selected with attention to obvious curvature changes in the data compilations. Table 12 summarizes the rating scheme to establish a pilot restriction. The form of the restriction is not specified, but any number of checkouts could be visualized. Every effort is made to produce an objective rating but the arbitrary nature of the rating cannot be removed altogether. If the total pilot rating is four points or less the restrictions apply.

EXAMPLES OF DETAILED ACCIDENT ANALYSES. Four cases are provided for review. Case numbers 3-1034, 3-1405 and 3-2445 are classified by NTSB as mismanagement of fuel as the probable cause whereas case number 3-2595 has been classified as improper operation of powerplant and powerplant controls by NTSB. The case reviews have identified cases 3-1405, 3-2445 and 3-2595 as preventable by both cockpit standardization and pilot restrictions while case number 3-1034 was identified as preventable by cockpit standardization only.

TABLE 12. PILOT RESTRICTION RATING

Qualification Element			Rating Points	Actuals*
1. Total flight time	=	300 hrs or more	1	
2. Total flight time	=	1,000 hrs or more	1	
3. Certificate	=	Commercial or higher	1	
4. Time in type	=	100 hrs or more	1	
5. Time in type	=	50% of total or more	1	
6. Latest 90-day in type	=	25 hrs or more	1	
7. Instrument rating			1	
8. Total instrument time	=	20 hrs or more	1	
9. Pilot owned aircraft			1	
		Total possible	9	

*Actual points which total 4 or better indicate not preventable by pilot restriction.

Case 3-1405. This was a rental at Duluth International Airport. The pilot is a lawyer with a private pilot certificate, single-engine-land (SEL). His total flying time was 253 hours, of which 51 were in type aircraft. His latest 90-day period had 9.2 hours, all in type. His pilot-in-command (PIC) total was 202 hours. The weather was overcast with drifting snow, winds 14-20 knots, temperature 22°F, dew point 17°F, visibility 10 miles, ceiling 900 ft. Time of flight: 0900 hours on February 22, 1977.

Description of flight. Pilot planned five touch-and-go practices. After three successful completions and climbing to 400 ft. above ground level (AGL), the engine failed without warning. At that point the plane was trimmed, no flaps, engine at 2500 rpm, and no carburetor heat. Position was over end of the runway. Pilot contacted tower, received landing runway instructions and clearance, and entered a power-off glide, turning to the right, believing at this point that he could land safely. However, he then noticed a tall stack in his path and turned left to avoid a collision. He then attempted to restart the engine by applying carburetor heat and priming, without success. Toward the end of the glide he attempted to switch to right main tank, but still could not restart. At this point, having lost speed and altitude, pilot became aware that he could not make runway so he leveled and prepared for ground impact. He struck a chain link fence and the plane came to rest with wings and engine separated from the fuselage.

Post-accident investigation. Examination of the tanks showed the left main to be nearly full while the right appeared empty with no signs of spillage; the tip tanks had about three gallons each. The carburetor heater was in the half-on position. The auxiliary pump was off. The pilot made no mention in his accident report of having put the auxiliary pump on. However, in responding to the examiner he did say he had put the auxiliary fuel pump on. He stated that during his preflight he had checked only the left main tank since that quantity was certainly adequate for the planned duration of the flight. The fuel selector valve was found positioned between left main and right main. Examination determined that no flow path existed at the position but that the flow path from either tank was clear. The throttle was found full open, the mixture full rich, the propeller set for high rpm, and the primer unlocked. The pilot stated that he had not looked at the selector during repositioning because he did not want to take his eyes off his flying. The personal injury is serious and the aircraft damage is substantial.

Rating analysis. Pilot errors are present in all categories. The pilot was not aware of two critical pieces of information. Obviously he never absorbed the fact that the right main tank was empty. Additionally he never appreciated the potential for icing even though his flying included substantial portions of low-powered glides. The fuel quantity gauges are conveniently arrayed on the instrument panel, four units side by side with no switching required, left-center and just above the manifold pressure and tachometer. Therefore, no points are assessed for gauge visibility or positioning. However, a low-fuel level warning light might have caught his attention. Similarly, an icing condition warning might have done the same. Two points are scored for each. An additional point is scored for the minimal treatment of carburetor icing contained in the manual.

Several decision errors were committed. The pilot apparently made an initial decision that a power-off landing would not be difficult and that an engine restart was not necessary. This is a false hypothesis but was not due to a difficulty in interpreting the available information or to any other reason associated with the cockpit configuration. Therefore no points are assessed in this area. However, when he later concluded that a restart was necessary, he did not form a correct operational decision. He failed to include the use of the auxiliary fuel pump in the decision. He was not certain where the carburetor heat had to be set nor how much time would be required for producing the desired effect. Clearly some aid in formulating a correct decision would have been helpful in this crisis situation, as for example a placard strategically placed for checking off the restart procedure. Two items at one point each were scored here.

Execution errors compounded the decision errors. The matter of the auxiliary fuel pump and carburetor heater can be assigned here if the assumption is made, based on the statement of the pilot, that he intended to apply each. Then the execution was faulty. Two points are assessed due to a possibility that the location of the boost pump switch did not lead the pilot instinctively to its use. No points are assigned for mispositioning the selector because the restart chances would not have been improved had the right main tank been placed in operation. Also, the false hypothesis that the right tank contained fuel has already been penalized.

A total of nine points is the rating. This is above the threshold value of six points. The conclusion is that the cockpit configuration, if optimized, offered reasonable chances of preventing the accident.

Pilot restriction analyses. The pilot's total flight time was 253 hours with 52 hours in type. His certification was private with a rating of single-engine-land. The pilot was not instrument rated. He logged a total of five hours in type over the last 90 day period prior to the accident but also logged 45 hours in "day-all makes". A total of 4.5 hours of simulated instrument time was logged by this pilot. Finally, the pilot was not the owner of the aircraft. In summary, the total number of points accumulated for this pilot is zero which establishes him as a candidate for pilot restriction countermeasures.

Case 3-1034. The pilot owns the aircraft. The pilot holds a commercial certificate, SELS. His total flight time was 3,000 hours, of which 250 hours were in type aircraft. His latest 90-day period had 3.0 hours, all in type. The weather was scattered clouds at 10,000 ft., with 4 knot winds, temperature 69°F, dew point 40°F, and visibility 55 miles. Time of flight: 1300 hours on May 7, 1978.

Description of flight. On the return to the airport, while cruising at 7,000 ft., the pilot noted that main tanks were one-quarter full. At that point, clearance to land was received and the descent was initiated. After flaps were set and landing gear lowered, pilot noticed that the engine quit. Pilot attempted restart by switching tanks from left to right and turning on the auxiliary pump using the HI position. The engine sputtered but did not start. Pilot switched back to left tank. Pilot attempted to land on a golf course but contacted trees before making the fairway, then impacted the ground in a level attitude. The copilot was fatally injured and the pilot seriously injured.

Post-accident investigation. The left wing fuel cell was found to contain about five gallons of fuel and an estimate was made that five additional gallons were lost through the severed fuel line. The right side tank was dry. The fuel selector was positioned to the left tank, and the auxiliary fuel pump switch was in the HI position. Mixture control was in the full rich position. After the wreckage was transferred to the airport, the engine was mounted on test stand and operated satisfactorily. Note that the pilot flight manual contains warnings that excessive use of the HI position on the auxiliary pump can cause flooding of the engine making restart difficult; use of this position should be momentary only during tank switching. Aircraft damage was rated as destroyed.

Rating analysis. In the perception category, there is one clear pilot error and a second is probable. The pilot stated that he checked fuel status before commencing the landing procedure but, nevertheless, he was not aware that the right tank was empty. Fuel quantity gauges are located on the right side of the instrument panel, in a high position, and do not require switching. It is not certain whether the right gauge was inaccurate or that the pilot misread the quantity. Visibility of the gauge is considered to be fair so one point is assessed for accuracy. Two additional points are assessed for lack of a low fuel warning. It is possible that the engine stoppage could be traced to aircraft maneuvering and uncovering of the left tank outlet line. The manual contains a warning that this is possible when fuel quantity is one-quarter tank full or less so no points are assessed in this regard. This aircraft is equipped with a fuel injection system so icing is not a high probability. However, an alternate air intake is provided; but the owner manual on this aircraft is vague on when it should be used. There is no coverage in the manual on the possibility of engine cooling during glide and on potentially harmful consequences, for which one point is assessed.

The main decision error was in the procedure the pilot would follow in attempting the engine restart. His apparent belief that the engine failure was due to exhaustion of fuel in the left tank was a false hypothesis. However, no points are assessed for interpretation of information. Neither are any points placed against the instruction manuals although very little assistance is provided for coping with an engine outage problem. His decision on restarting was incorrect and might have been different if more analysis time were available. With a more nearly optimized cockpit, some additional time might have accrued and one point is assigned. Similarly, some assistance from decision aids such as a checklist might have produced a better restart decision.

Execution of the restart attempt was faulty. Tank switching was executed correctly but this brought an empty tank on line due to previous errors which have already been penalized. However continued execution of the false hypothesis lost valuable time for the restart and two points are assessed. Then, after returning to the left tank, the continuous use of high boost, contrary to instructions, constitutes a mispositioned actuator, for which two points are assigned.

The total of ten points is indicative of a potential for avoidance of the accident through cockpit standardization.

Pilot restriction analysis. The pilot has a total of 3000 hours with 250 in type. In the last 90 days prior to the accident, the pilot has logged a total of three hours all of which was in type. The pilot holds a commercial certification with a single-engine-land rating. The pilot is not instrument rated and has not logged either simulated or actual instrument time. The pilot is the owner of the aircraft. The total number of points accumulated for this pilot with regard to the rating scheme is five and therefore over the threshold of four.

Case 3-2445. This was a rental at Honolulu International Airport. The pilot, deceased as a result of the accident, was an automobile leasing agent. He held a private pilot certificate, SEL. His total flying time was 276 hours, of which 2.5 was in type; however, only 1.7 hours were as PIC. His latest 90-day period included 14 hours of dual flying and 20 hours as PIC. The weather was scattered clouds at 2500 ft., ceiling at 4500 ft., visibility 25 miles, winds at 17 knots, temperature 84°F, dew point 62°F. The flight commenced at Honolulu at 0953 hours on August 11, 1976.

Description of flight. The flight went to the island of Maui and included a landing at Molokai Airport. The stay there was brief, the engine remained running, and no fuel was taken on. At about 1120 hours, the aircraft returned to the Honolulu airport and landed successfully. A few minutes later the flight resumed with a normal takeoff. While climbing at about 300 feet the engine commenced to cut in and out but then quit entirely. Based on passenger statements, the pilot attempted a restart by switching the selector from the left main tank to the right main tank but did not succeed in getting the engine back in operation. Apparently the switching was done after several immediate attempts to restart on the left main tank were unsuccessful. The auxiliary pump had been switched on. In attempting a power-off landing, the pilot experienced difficulty with the control wheel and was not able to make the nearby runway. The aircraft impacted the ground in a left wing down attitude and caught fire. The passenger in the right front seat reported that the flight had been made entirely on the left main tank and that the gauge had read nearly full for the entire time. The statement indicates that the pilot was unaware of the need to switch the gauge to read fuel quantity on either side and that the gauge was reading the right main tank all the while.

Post-accident investigation. It was determined that the preflight briefing dealt mainly with traffic patterns and restricted military areas, with very little coverage of the cockpit and controls. The fire had been brought under control quickly so that some control settings could be verified. The selector was in the right main position. The main fuel gauge showed full on the right side. In addition to the fatal injuries to the pilot, there were two serious and one minor passenger injuries. The aircraft was destroyed by the accident.

Rating analysis. The pilot committed major errors of perception. He had no information on fuel status. Since gauge switching is required, two points are assessed. The passengers had been aware of the gauge readings so no points are included for visibility. A low-fuel warning would have alerted the pilot in time for a successful tank switch so two points are assessed.

At least two decision errors were committed. The hypothesis that the left tank was nearly full after several hours of flying is the most obvious. Manuals provide a pilot with guidance on fuel consumption during flight at various power levels but, in the case of this pilot, more emphasis or clarity would have been necessary. A point is assessed here. Apparently the first operational decision was that the engine could be restarted without tank switching. At that time, the pilot workload and analysis time were both crucial since he had limited altitude for regaining power. Three items are assessed one point each.

Several pilot errors are present in execution. Based on the statements concerning the measures taken by the pilot in attempting the restart, it can be concluded that he continued on the false hypothesis for too long a time. Had all the instruments and controls contributed, by their positioning, to a coordinated action, there might have been time to regain power, so two points are assessed. Additionally, a placard or some source of instruction might have helped so another point is included. It is also conceivable that there was a delay in execution of a (revised) decision due to the difficulty in reaching the selector valve, which is in fact in one of the more difficult positions. Thus, two points are added here.

This accident analysis produces a total of twelve points, one of the higher values of those cases presented in detail. It is also to be noted that the cockpit in question has an arrangement with some significant departures from the standardization guidelines.

Pilot restriction analysis. The pilot had 276 total hours with three hours in type. In the last 90 days prior to the accident, the pilot logged

1.7 hours in type and 17.0 hours in other models. The pilot's certificate was private with a rating of single engine land. The pilot is not instrument rated and has recorded a total of 8.2 hours of simulated instrument time. The pilot is not the owner of the aircraft. The total number of points accumulated with regard to the rating scheme is zero. This pilot is a candidate for pilot restriction countermeasures.

Case 3-2595. The pilot is the owner of the aircraft. He is a service engineer with a private pilot certificate, SEL. His total flying time, was 282 hours with 224 as PIC. Of the total time, the time in type is 189 hours. The weather was clear, visibility 15 miles, light winds, temperature 80°F, humidity unknown. Time of flight: 1039 hours on September 2, 1978.

Description of flight. Flight departed Cincinnati on a VFR flight plan, had one stop at which fuel tanks were topped off, and approached the Conneaut Lake, Pennsylvania airport. Pilot observed the wind direction, selected a runway, and applied full flaps. The landing path was excessively steep, the aircraft bounced, and the pilot initiated a go-around. The climb was slow as the pilot had failed to remove carburetor heat. His action at that point was to retract the flaps 10°. However, the flaps did not lock into the intended position and slipped back another notch. As lift was lost the aircraft settled back to the ground. Pilot cut off the engine but went off the end of the runway, contacted a fence, and came to rest in an adjacent field. The report does not state whether the pilot followed checklist procedures before landing and when attempting to climb, as for example correct mixture settings.

Post-accident investigation. The aircraft was substantially damaged, including the separation of the nose gear, deformation of the propeller, cowling, motor mount, and firewall. There were no personal injuries. The pilot stated that carburetor heat was not removed when the decision was made to abort the landing. The recommendation of the pilot was that the flaps should not have been repositioned until after more altitude had been gained.

Rating analysis. Commencing at the point where the pilot attempted to climb after the unsuccessful landing, there is at last one perception error. The pilot was not aware, at that moment, that the carburetor heat was still on. Since the actuator (handle) for this control is not located in the preferred position as noted in standardization guidelines and is not as conspicuous as it might be, two points are assessed. Additionally, gauges for monitoring engine performance are inadequate, with no gauge for manifold pressure, so two additional points are assessed. There is no information on whether mixture control was properly set but the checklists in the manuals are very clear on this matter so no points are assigned here.

The pilot formed a false hypothesis in expecting that flap retraction would solve the problem. However, perception rather than interpretation is the root of his difficulty and those points are noted above. Nevertheless, in a cockpit configured for workload simplification and with some decision aids available, he might have been led to a more effective decision. Two points are assessed in the decision category.

In this accident, given the poor decision on steps to continue a climbing maneuver, execution points would be redundant and are not assessed. However, the continued execution of a false hypothesis might have been forestalled had instruments and control been arranged in the coordinated manner of the standardization guidelines. It should have been possible to quickly observe that powerplant settings were improper for generating the necessary climb power. Since the pilot had no inducement to correct his decision, three points are assessed.

This accident is rated at nine total points and is classified as preventable by standardization. Only the improper powerplant control actions are considered. No points were included for mispositioning the flap actuator.

Pilot restriction analysis. The pilot had a total of 282 hours with 189 hours in type. In the last 90 days prior to the accident, the pilot logged 12.9 hours total with 11.5 hours in type. The pilot's certification was private with single-engine-land rating. The pilot is not instrument rated. The pilot has logged a total of 15.9 hours of both simulated and actual instrument time. The pilot is the owner of the aircraft. The total number of points accumulated with regard to the pilot rating scheme is three. This total is one short of the cutoff of four and therefore a candidate for pilot restriction countermeasures.

THE COUNTERMEASURE ACCIDENT DATA BASE.

The results of the case review process, which included the completion of the initial countermeasure assignment sheets (Tables 7 and 8 shown earlier in the text) and the countermeasure ratings, identified 47 accidents as preventable by standardization and/or pilot restriction. Making up the 47 accidents are 35 accidents which belong to the mismanagement of fuel category and 12 accidents which belong to the improper operation of powerplant and powerplant control category. Table 13 identifies the 47 accidents within the preventable by standardization and preventable by pilot restriction subsets. This table also identifies those cases which have been classified as both -- preventable by standardization and preventable by pilot restriction.

A few remarks can be made about the cases not included in the countermeasures group. The accidents rated as not preventable by other standardization or pilot restriction contain pilot errors that may be very difficult to suppress. Many of the crucial errors in the not preventable group involve pure failures of omission in recommended and published procedures. Typical examples include a failure to assure that a known and adequate supply of fuel is onboard for the flight, failure to visually check fuel and engine oil during preflight inspection, and failure to assure familiarity with aircraft systems during checkout. Numerous cases were found of poor judgment during in-flight planning including failure to estimate fuel consumption required for changes in the flight plan or failure to anticipate that adverse weather would force a change in flight plan.

TABLE 13. COUNTERMEASURE CASES

Mismanagement of Fuel:

1. Preventable by Standardization (26 accident cases)

Case No.	Injury Severity	Case No.	Injury Severity
3-0540*	Fatal	3-2442*	Minor
3-0985	Fatal	3-4128	Serious
3-1034	Fatal	3-1258*	Minor
3-2363	Fatal	3-0710	Fatal
3-3061*	Fatal	3-0812	Minor
3-3577	Minor	3-2445*	Fatal
3-1255	Minor	3-2245*	Property Damage
3-2990	Serious	3-1646*	Fatal
3-2483	Fatal	3-2343*	Serious
3-0012	Minor	3-3234*	Serious
3-1174*	Fatal	3-3617	Fatal
3-1219	Fatal	3-4201*	Fatal
3-0159*	Serious	3-1405*	Serious

*Also preventable by pilot restriction.

2. Preventable by Pilot Restriction (22 accidents)

Case No.	Injury Severity	Case No.	Injury Severity
3-2839	Serious	3-2442*	Minor
3-0965	Minor	3-1258*	Minor
3-2343*	Serious	3-2392	Fatal
3-1156	Minor	3-2445*	Fatal
3-0028	Minor	3-2245*	Property Damage
3-3234*	Serious	3-0159*	Serious
3-4060	Fatal	3-0540*	Fatal
3-4201*	Fatal	3-0512	Fatal
3-1646*	Fatal	3-3061*	Fatal
3-2423	Fatal	3-1174*	Fatal
3-3033	Fatal	3-1405*	Serious

*Also preventable by standardization.

TABLE 13. COUNTERMEASURE CASES
(Continued)

Improper Operation of Powerplant and Powerplant Controls:

1. Preventable by Standardization (9 accidents)

Case No.	Injury Severity	Case No.	Injury Severity
3-0037*	Serious	3-1880*	Fatal
3-3197	Serious	3-0424	Fatal
3-2595*	Minor	3-0083*	Serious
3-2622	Fatal	3-0103*	Serious
3-0744	Fatal		

*Also preventable by pilot restriction.

2. Preventable by Pilot Restriction (8 accidents)

Case No.	Injury Severity	Case No.	Injury Severity
3-0103*	Serious	3-0083*	Serious
3-1880*	Fatal	3-2595*	Minor
3-3406	Fatal	3-1627	Minor
3-2667	Minor	3-0037*	Serious

*Also preventable by standardization.

COUNTERMEASURE INJURY SEVERITY. The 47 countermeasure accidents consisted of 23 fatal accidents, 11 serious accidents, 12 minor accidents, and one property damage only accident. Table 14 provides an overview of the countermeasure injury severity to both the population (2011) and sample (200) accidents.

TABLE 14 INJURY SEVERITY

Data Base	Fatal	Serious	Minor	Property Damage	Total
2011 Population	174	275	451	1111	2011
200 Sample	99	42	29	30	200
47 Countermeasure	23	11	12	1	47

Comparison of the distribution of cases by severity index across the several accident groups discloses some interesting points. Of the 47 accidents in the countermeasures group, 49 percent are fatal. This is practically identical to the proportion of fatal accidents in the sample of 200 accidents. The indication here is that the fatal accidents are as preventable as the countermeasures group taken overall. The same observation applies to the serious level of accidents. The only change occurs in the two lowest levels. Minor accidents are up and property damage only are down, as proportions, in the comparison of the countermeasures cases to the sample.

RELATED INSTRUMENT AND NIGHT TIME. A review of the ratings for the 200 sample accident pilots shows that roughly 32 percent (64 pilots) hold instrument ratings. A review of the NTSB data files for all 200 sample pilots shows that 82 percent of the pilots have never logged actual instrument time, 83 percent of the pilots have never logged simulated instrument time, and 76 percent of the pilots have never logged night time. A comparison between the percentages for the 47 countermeasure accidents and for the sample is shown in Table 15 where the two sets are very close. However, the usefulness of these results is limited due to apparent discrepancies in extracting the data from pilot logs onto accident reports.

TABLE 15. RELATED INSTRUMENT AND NIGHT TIME

	200 Accident Population	47 Countermeasure Accidents
No Actual Instrument Time	81.7%	82.9%
No Simulated Instrument Time	83.2%	82.9%
No Night Time	76.2%	72.3%

These figures support the findings that the sample and countermeasure accident pilots do not practice or utilize instruments to the level that may be necessary as supported by the fact that 21.3 percent of the sample accidents and 36.4 percent of the countermeasure accidents occurred at night. When these statistics are combined with the 10 percent IFR conditions at the time of the accident, a severe problem is recognized. In addition, it was determined that only 12.8 percent (6 pilots out of 47) of the countermeasure accident pilots held current instrument ratings.

OWNER VS. RENTER. Table 16 compares the 47 countermeasure accident pilots to the 200 sample pilots. We note that there is a significant increase in renters within the countermeasure accidents (from 26.5 percent to 40.5 percent). At the same time, the percentage of owners in both sets of data remain the same and the percentage of employees drops considerably. Employees may or may not be assigned to fly a particular make/model as part of their duties and thus may exhibit characteristics of either group.

TABLE 16. OWNER/RENTER COMPARISON

	200 Accident Population	47 Countermeasure Accidents
Renters	53	19
Owners	77	18
Employees (Charter/Corporate Pilots)	40	3
Unknown	17	7
Not Received	13	--

PILOT OCCUPATION. A look at the occupations of those pilots for which the accidents have been assigned countermeasures does not reveal any specific occupational trend worth studying. The highest frequencies of occupations for pilots involved in mismanagement of fuel countermeasure accidents include professional pilots and company executives while the occupations for pilots involved in improper operation of powerplant and powerplant control countermeasure accidents include mechanics.

LIGHT CONDITIONS. In supporting previous statements concerning instrument time training, etc., Table 17 provides a comparison of the light conditions for the 200 sample accidents and the 47 countermeasure cases.

TABLE 17. LIGHT CONDITION COMPARISON

	200 Sample Accidents	47 Countermeasure Accidents
Daylight	71.8%	58.2%
Dusk	6.9%	6.3%
Dark Night	16.3%	29.2%
Moon Night	5.0%	6.3%

A sharp increase in night accidents from 21.3 percent to 36.2 percent is noted. With regard to nighttime hours, it was already established that the percentage of pilots who have not logged night time is 76.2 percent for the 200 sample accidents and 72.3 percent for the 47 countermeasure accidents. In a closer review of the 47 countermeasure accidents, we find 15 of the 47 accidents (31.9 percent) occurred between the times 8:00 p.m. and 5:00 a.m. In addition, within the 15 accidents, six pilots (40 percent) had not logged night time in the last 90 days.

TOTAL HOURS AND HOURS IN TYPE. The statistics on the 47 countermeasure accident pilots (as compared to the 200 sample accidents) also indicate that the average pilot is well experienced in total hours and hours in type. The average total hours for pilots involved in mismanagement of fuel accidents is 1134 hours while the average hours in type for these pilots is 216.2 hours. For those pilots involved in improper operation of powerplant and powerplant control accidents, the average total hours is 822 hours with 93.1 hours in type. Table 18 provides a comparison of these averages to the sample accidents.

TABLE 18. COMPARISON OF PILOT HOURS

	200 Sample Accidents*	47 Countermeasure Accidents
Mismanagement of Fuel		
1. Avg. Total Hours	2101.9(621.5)	1133.9(300.5)
2. Avg. Hours in Type	299.7(51.8)	216.2 (32.5)
Improper Operation of Powerplant and Powerplant Controls		
1. Avg. Total Hours	2902.6(1398.5)	821.7(261.5)
2. Avg. Hours in Type	217.0 (55.5)	93.1 (9.3)

*Number in parenthesis represents median.

RECENCY OF EXPERIENCE. Recency of experience in this study has been defined as time in type within the last 90 days. The pilots within the 47 countermeasure accidents who logged time in the last 90 days show the average time in type for the mismanagement of fuel category to be 16.5 hours while the improper operation of powerplant and powerplant control category is 13.5 hours. The figure which is significant is that 17 pilots within the 47 countermeasure accidents (36.2 percent) did not log time in type in the last 90 days prior to the accident. Tables 19 and 20 provide a listing of the 47 countermeasure accident cases with the recency of experience recorded.

Another interesting finding generated from a review of the time in type hours over the last 90 days is that 21 pilots within the 47 countermeasure accidents (44.7 percent) logged time in other than the accident aircraft during the period. This determination was calculated by adding together the "Day All Models" and "Night All Models" figures from the NTSB Form 6120.4 and then subtracting the hours in type. If there is a balance, the pilot must have flown another aircraft within the time period. For those pilots logging time in other than the accident aircraft, the average is 46.7 hours for the 90 day period. This figure is considerably higher than the average time in type previously stated.

TABLE 19. RECENCY OF EXPERIENCE: LAST 90 DAYS
Mismanagement of Fuel

Case No.	Day All Models +	Night All Models −	Accident Make/Model =	Other Aircraft
3-0540	49.3	1.7	0.0	51.0
3-0985	0.0	0.0	0.0	0.0
3-1034	3.0	0.0	3.0	0.0
3-2363(1)				
3-3061	19.0	0.0	19.0	0.0
3-3577	31.4	3.0	15.8	18.6
3-1255(2)				
3-2990(1)				
3-2483(1)				
3-0012	0.0	0.0	0.0	0.0
3-1174	0.0	0.0	0.0	0.0
3-1219	4.0	0.0	4.0	0.0
3-0159	1.0	0.0	1.0	0.0
3-2442	11.0	0.0	7.0	4.0
3-4128	235.0	16.0	14.0	237.0
3-1258	20.0	2.5	20.0	2.5
3-0710(1)				
3-0812	131.8	15.6	46.8	100.6
3-2445	17.0	1.7	1.7	17.0
3-2245	26.6	10.7	2.0	35.3
3-1646	13.0	4.0	17.0	0.0
3-2343	0.0	0.0	6.8	0.0
3-3234	11.7	0.0	11.7	0.0
3-3617	80.0	0.0	80.0	0.0
3-4201	6.0	5.0	15.9	0.0
3-1405	0.0	0.0	9.4	0.0
3-2839	0.0	0.0	8.6	0.0
3-0965	0.0	0.0	36.4	0.0
3-1156	0.0	0.0	0.0	0.0
3-0028	13.3	6.0	2.9	16.4
3-4060	27.0	0.0	19.0	8.0
3-2423	0.0	0.0	0.0	0.0
3-3033	8.0	9.0	0.0	17.0
3-2392	85.0	5.0	2.0	88.0
3-0512	34.4	.9	35.3	0.0

Notes: (1) Pilot logbooks not found.
(2) Pilot log not readible in NTSB report.

TABLE 20. RECENCY OF EXPERIENCE: LAST 90 DAYS
Improper Operation of Powerplant and Powerplant Controls

Case No.	Day All Models +	Night All Models -	Accident Make/Model =	Other Aircraft
3-0037	34.8	0.0	34.8	0.0
3-3197	33.0	1.0	34.0	0.0
3-2595	12.9	0.0	11.5	1.4
3-0103	31.9	9.6	2.5	39.0
3-1190	100.0	0.0	3.3	96.7
3-1880	0.0	0.0	0.0	0.0
3-2500	15.0	10.0	10.0	15.0
3-3406	0.0	0.0	0.0	0.0
3-1838	12.0	0.0	12.0	0.0
3-2667	69.6	5.4	7.5	67.5
3-2622	0.0	0.0	0.0	0.0
3-0083	31.3	4.1	2.8	32.6
3-0683	110.0	15.0	6.0	119.0
3-0744	0.0	0.0	0.0	0.0
3-0424	16.0	0.0	0.0	16.0
3-2659	25.0	0.0	0.0	25.0
3-1627	19.0	1.4	1.4	19.0

ADDITIONAL CAUSE/FACTORS. There are six additional cause/factors besides mismanagement of fuel and improper operation of powerplant and powerplant controls which are considered appropriate for further review when linked to the two major cause/factors. These six cause/factors are:

1. Diverted attention from the operation of the aircraft.
2. Failed to use or incorrectly used miscellaneous equipment.
3. Improper in-flight decisions or planning.
4. Inadequate supervision of flight.
5. Lack of familiarity with aircraft (model).
6. Spontaneous, improper action.

Table 21 provides a listing of the frequencies that each additional cause factor was found on the NTSB data files for the 35 mismanagement of fuel countermeasure file. The cause/factor "improper in-flight decisions or planning" is by far the most frequent (69.2 percent of the total). This figure corresponds to the 63.7 percent in-flight (phase of flight operations) for fatal accidents only.

TABLE 21. ADDITIONAL CAUSE/FACTORS
(35 Countermeasure Accidents Involving
Mismanagement of Fuel)

Additional Cause/Factor	No. of Accidents
1. Diverted attention from operation of aircraft.	0
2. Failed to use or incorrectly used miscellaneous equipment.	0
3. Improper inflight decisions or planning.	9
4. Inadequate supervision of flight.	0
5. Lack of familiarity with aircraft (model).	2
6. Spontaneous, improper action.	2
Total Accidents	13

Table 22 provides a listing of the figures for the 12 countermeasure accidents recorded as improper operation of powerplant and powerplant controls.

TABLE 22. ADDITIONAL CAUSE/FACTORS
(12 Countermeasure Accidents Involving
Improper Operation of Powerplant and Powerplant Controls)

Additional Cause/Factor	No. of Accidents
1. Diverted attention from operation of aircraft.	0
2. Failed to use or incorrectly used miscellaneous equipment.	2*
3. Improper in-flight decisions or planning.	1
4. Inadequate supervision of flight.	0
5. Lack of familiarity with aircraft (model).	0
6. Spontaneous, improper action.	0
Total Accidents	3

*Refer to "anti-icing/deicing equipment - improper operation of/or failed to use."

Except for the "improper in-flight decisions or planning" cause/factor for the mismanagement of fuel accidents, there are few additional cause/factors assigned.

Standardization and Pilot Restriction Ratings. Tables 23 and 24 provide summaries of both the standardization and pilot restriction rating charts. The standardization summary shows that the highest recordings were in the area of execution errors where "visibility of controls inadequate" and "control in difficult position." Perception errors also had high frequency items which included "visibility of gauge is poor" and "gauge not optimally positioned." The high frequency in "workload affected by cockpit configuration" is what one would expect for the high frequencies previously mentioned.

TABLE 23. SUMMARY OF STANDARDIZATION COUNTERMEASURE RATING CHARTS
(47 Countermeasure Accidents)

Perception Errors:	
Indicator/gauge not accurate	4
Visibility of gauge is poor	15
Indicator/gauge requires switching	9
Gauge not optimally positioned	17
No warnings available	12
Instruction manuals lack warnings	10
Pilot Formed False Hypothesis:	
Interpretation of information is difficult	14
Instruction manuals ambiguous	12
Operational Decision Incorrect:	
Workload affected by cockpit configuration	18
Analysis time affected	11
Decision-aid checklist unavailable	4
Instructions, procedures inadequate	3
Execution Errors:	
Selected incorrect actuator	3
Mispositioned actuator	16
Positioned actuator to unintended setting	3
Visibility of controls inadequate	23
Failed to position actuator	10
Control in difficult position	24
Control operation is complicated	9
Instrument/controls uncoordinated	10
Placards, instruments not available	3

TABLE 24. SUMMARY PILOT RESTRICTION RATINGS
(47 Countermeasure Accidents)

	Frequencies
Total flight time = 300 hours or more	26
Total flight time = 1,000 hours or more	13
Certification = Commercial or higher	11
Time in type = 100 hours or more	13
Time in type = 50% of total or more	7
Latest 90 day in type = 25 hours or more	9
Instrument rating	10
Total instrument time - 20 hours or more	11
Pilot owned aircraft	10

COST ESTIMATES OF ACCIDENTS.

In view of the vagueness in the use of the term safety benefits, a growing tendency is the determination of economic values that might accrue from measures that reduce accidents. Then, with monetary quantities, serious accidents carry more weight in summary compilations; and minor events, which might have a higher frequency of occurrence, do not distort results. The FAA makes full use of economic values in planning and evaluating its regulatory programs.

ELEMENTS OF COST. A breakdown, according to commonly used methods, facilitates the compilation of monetary values and preserves comparability with related studies. Essentially, we are concerned with the categories of personal injury, aircraft damage, and other property damage as applicable.

Personal Injury. Accidents involving both automobiles and aircraft result in very large losses to individuals and to society as a whole. Personal injury costs dominate the accident costs. In order to assess the losses, it becomes necessary to assign monetary values to personal injuries. Within the Department of Transportation, there are several studies of the problem and some of the published results provide the base for the values in this study.

Fatalities. The approach in a National Highway Traffic Safety Administration report (Reference 13) is the computation of production losses for a victim of an accident. The losses are both the compensation the individual would have received for work connected service and the service he might have provided to the community, which would probably not be compensated. For fatalities, the production loss covers work over the victim's life span from ages 20 to 65, or that remaining at the time of death. For non-fatal injuries, there is a scale of severity for which medical expense varies as well as lost production time. The results, as found for the year 1975, value a fatality at $283,000 with injuries in the range of $188,000 downward to $400 with an average of $1,360.

For aviation accidents, the values have been found to be somewhat higher. For the year 1974, the value of a fatal injury was found to be $300,000 on the basis of accident claims settlements (Reference 14). At that same time, serious injuries were $45,000, also based on claims settlements, and minor injuries were $6,000. Since that time, settlements have increased to an average level of $503,000 in 1979. A very similar result is found from a calculation on the value to self and others approach. This method produces a value of $530,000 for 1980 for a statistical air traveler (Reference 5). This value is selected for the cost analysis of this work.

General aviation occupants are found to produce a higher valuation of a statistical life on the value to self and others approach than the average of all air carrier occupants. The result is 13 percent higher. This consideration further supports the selection of the higher value, as opposed to other approaches to life valuation.

Non-fatal Injuries. The efforts of analysts to produce useful values for statistical accident injuries contain even greater divergence. The first problem is to segregate serious and minor injuries. An arbitrary but widely used level for demarcation is $20,000. Next, the results of the several methods are compared. In the case of accident injuries, the claims settlements approach produces higher results by far than the other methods. However to maintain consistency, the value to self and others method is again preferred. The results show a value of $38,000 for serious injuries and $5,000 for minor injuries. These values are used in the accident cost analysis.

It may be noted again that general aviation accident occupants do not produce the same values as air carrier occupants. In this case, the general aviation group is lower due to a great reduction in accident investigation expense which more than offsets the higher earning power of the group. The difference is about 15 percent. However, this difference is not so well established as to make the more standard value unsatisfactory.

Damaged Aircraft Cost. Aircraft may be destroyed or damaged at either of two levels - substantial or minor/none. For analytical purposes, general aviation aircraft have been aggregated into categories on the basis of size, powerplants, and gross weight. There are separate categories for rotary wing craft and agricultural planes. Then the question becomes one of determining or assigning values to the categories. The most widely used approach is to simply take the market value of a replacement aircraft. In this way, account is taken of depreciation and obsolescence to a major degree. Obviously, there may be differences of the replacement value with respect to original value due to preferences of purchasers which show up in the used aircraft market. Economic conditions may also influence the year to year values.

The purposes of the present study are best served by using the replacement value approach but bypassing the categorization of aircraft. Thus the Blue Book of Aviation (Reference 15) is used for values of each individual destroyed aircraft. Use of the categories as a guide to cost would only detract from the precision of costing and save only a minor amount of work. The values are found for the year of the accident and converted to 1980 dollars.

For damaged aircraft the restoration value must be estimated in a general way. It was noted earlier that an attempt to price repair work for individual accidents was not feasible with any assurance of accuracy. The most widely accepted estimating procedure is to use one-third the replacement value as the cost for substantial damage. This value is derived by Noah (Reference 7) from insurance experience and is at the low end of the spread. Minor damage is rated as negligible and bracketed with cases of no damage. Damage costs are also determined for the year of the accident and converted to 1980 dollars.

Property Damage. This category of costs covers any property that is demolished or damaged as a consequence of the accident. The kinds of property that might be included are: buildings, posts carrying electric power, telephone wires, lights, fences, automobiles and mobile equipment, farm crops, or whatever might be in the path of an emergency landing. The cost is the best estimate of the replacement or repair of the damaged property.

ACCIDENT COST ESTIMATES. All accidents rated as preventable by either cockpit standardization or by pilot restriction have been costed. Throughout all the cost compilations, the results for the two types of accident prevention have been maintained separately. Also, the two types of pilot error - mismanagement of fuel and improper operation of powerplant and powerplant controls - are segregated. The results are shown in Tables 25 through 28. It can be observed in the tables that many accidents involve multiple occupants of the aircraft.

The most striking observation of scanning the tables is that the total costs are dominated by the personal injury items. Accidents containing fatalities are substantially more costly than those containing serious and minor injuries. Note also that even in non-fatal accidents, the personal injuries still exceed the aircraft costs with only a few minor exceptions. It is also noteworthy that most of the fatal accidents also include serious injuries, indicating that survivors are the general rule.

In reviewing these results it should be recalled that the sample of 200 accidents selected from the 2,011 accidents available in the failure category under study contains 49.5 percent of fatal accidents. This is due to the sampling allocation technique designed to produce an optimum sample on the basis of cost variance. Since the total NTSB accident population contains 6.1 percent of fatal accidents, extrapolations from the sample to the full category must be made accordingly.

The total costs found for the accident groups in Tables 25 through 28 have very little significance as absolute values. This is due to the formation of the sample, with its preponderance of fatal and serious accidents. Also, there are duplications in the tables. In the mismanagement of fuel group, 13 cases are found to be preventable either by standardization or by pilot restrictions, and therefore appear in the total cost for each group. In the improper operation of powerplant and powerplant controls group, five cases are preventable either by standardization or by pilot restrictions, and also appear twice in the totals. Without duplication, the preventable accidents are 47 in number with 35 being in the mismanagement of fuel group and 12 being in the improper operation of powerplant and powerplant controls group. The

TABLE 25. COSTS BY ACCIDENT CASE
Mismanagement of Fuel - Preventable by Standardization

Case No.	Aircraft Cost			Fatality	Injury Cost		Property	Total
	Dest.	Sub.	Min.	Cost	Ser.	Min.	Damage	
3-0540	$38,333			$ 530,000	$76,000			$ 644,333
3-0985	12,312			1,590,000	38,000			1,640,312
3-1034	38,417			530,000	38,000	$20,000		626,417
3-2363	7,074			530,000	38,000			575,074
3-3061	12,100			530,000	38,000			580,100
3-3577	19,360					15,000		34,360
3-1255	8,785					15,000		23,785
3-2990	2,087				38,000		$10,000	50,087
3-2483	21,222			530,000			10,000	561,222
3-0012		$ 6,281				5,000		11,281
3-1174	10,000 (kit)			530,000	38,000			578,000
3-1219	8,852			530,000	38,000			576,852
3-0159	15,079				38,000			53,079
3-2442		660				10,000		10,660
3-4128	40,731				38,000		750	79,481
3-1258		12,650				5,000		17,650
3-0710	24,170			530,000			750	554,920
3-0812		16,746				10,000	10,000	36,746
3-2445	29,280			1,060,000	76,000	5,000		1,170,280
3-2245		7,537					1,500	9,037
3-1646	18,526			1,060,000	38,000			1,116,526
3-2343		5,790			38,000	10,000		53,790
3-3234	25,766				38,000	5,000		68,766
3-3617		5,051		530,000	38,000			573,051
3-4201	27,830			1,590,000				1,617,830
3-1405		10,761			38,000		1,000	49,761
Subtotal	359,924	65,476		10,070,000	684,000	100,000	34,000	$11,313,400

TABLE 26. COSTS BY ACCIDENT CASE
Mismanagement of Fuel - Preventable by Pilot Restriction

Case No.	Aircraft Cost			Fatality Cost	Injury Cost		Property Damage	Total
	Dest.	Sub.	Min.		Ser.	Min.		
3-2839	$61,218				$190,000	$5,000		$ 256,218
3-0965		$2,723				5,000		7,723
3-2343		5,790			38,000	10,000		53,790
3-1156		660				20,000		20,660
3-0028		2,087				10,000		12,087
3-3234	25,766				38,000	5,000		68,766
3-4060	13,310			$1,060,000			5,000	1,078,310
3-4201	27,830			1,590,000				1,617,830
3-1646	18,526			1,060,000	38,000			1,116,526
3-2423	35,868			530,000				565,868
3-3033	32,300			2,650,000				2,682,300
3-2442		660				10,000		10,660
3-1258		12,650				5,000		17,650
3-2392	62,023			530,000	76,000	10,000		678,023
3-2445	29,280			1,060,000	76,000	5,000		1,170,280
3-2245		7,536					1,500	9,036
3-0159	15,079				38,000			53,079
3-0540	38,333			530,000	76,000			644,333
3-0512	39,930			530,000	38,000			607,930
3-3061	12,100			530,000	38,000			580,100
3-1174	10,000 (kit)			530,000	38,000			578,000
3-1405		10,761			38,000		1,000	49,761
Subtotal	421,563	42,867		10,600,000	722,000	85,000	7,500	$11,878,930
TOTAL								$23,192,330

TABLE 27. COSTS BY ACCIDENT CASE
Improper Operation of Powerplant and Powerplant Controls - Preventable by Standardization

Case No.	Aircraft Cost			Fatality Cost	Injury Cost		Property Damage	Total
	Dest.	Sub.	Min.		Ser.	Min.		
3-0037		$3,300 (kit)			$ 76,000			$ 79,300
3-3197		4,392			38,000	$10,000		52,392
3-2595		4,085				10,000	$1,200	15,285
3-2622	$19,965			$2,120,000				2,139,965
3-0744	28,600			1,060,000				1,088,600
3-1880	9,150			530,000	114,000			653,150
3-0424	38,332			530,000	38,000			606,332
3-0083	16,940				38,000	10,000		64,940
3-0103		4,891			38,000	15,000		57,891
Subtotal	112,987	16,668		4,240,000	342,000	45,000	1,200	4,757,855

TABLE 28. COSTS BY ACCIDENT CASE
Improper Operation of Powerplant and Powerplant Controls - Preventable by Pilot Restriction

Case No.	Aircraft Cost			Fatality Cost	Injury Cost		Property Damage	Total
	Dest.	Sub.	Min.		Ser.	Min.		
3-0103		$ 4,582			$ 38,000	$15,000		$57,582
3-1880	$ 9,150			$ 530,000	$114,000			653,150
3-3406	6,982			530,000	38,000			574,982
3-2667		16,032				5,000		21,032
3-0083	16,940				38,000	10,000		64,940
3-2595		4,085				10,000	$ 1,200	15,285
3-1627		14,252				20,000		34,252
3-0037		3,300 (kit)			76,000			79,300
Subtotal	33,072	42,251		1,060,000	304,000	60,000	1,200	1,500,523
TOTAL	146,059	58,919		5,300,000	646,000	105,000	2,400	6,258,378

cost totals do lend themselves to comparisons between the several accident groups. Obviously, the costs of individual accidents serve the essential purpose of providing average costs by accident severity index -- from which the annual accident costs can be constructed.

Average Accident Cost. Looking ahead to the extrapolation, the necessary data will need to show the average accident cost by severity. These data are presented in Table 29. Note that the fatal accidents run between nine times and 18 times the cost of the serious injury accidents. The variance in the average cost of a fatal accident is more related to the number of passengers and whether any survived than to the technical details of the accident. The results, as seen here, are a graphic illustration of the necessity to over sample in the fatal and serious accidents.

TABLE 29. COSTS BY ACCIDENT SEVERITY

Mismanagement of Fuel	No.	Totals	Average
A. Preventable by Standardization:			
Fatal	13	$10,814,917	$ 831,917
Serious Injury	6	354,964	59,161
Minor Injury	6	134,482	22,414
Property Damage Only	1	9,037	9,037
Subtotal	26	$11,313,400	$ 435,131
B. Preventable by Pilot Restriction:			
Fatal	11	$11,319,500	$1,029,045
Serious Injury	5	481,614	96,323
Minor Injury	5	68,780	13,756
Property Damage Only	1	9,037	9,037
Subtotal	22	$11,878,931	$ 539,951
Improper Operation of Powerplant and Powerplant Controls	**No.**	**Totals**	**Average**
C. Preventable by Standardization:			
Fatal	4	$ 4,488,047	$1,122,012
Serious Injury	4	254,523	63,631
Minor Injury	1	15,285	15,285
Property Damage Only	0	0	0
Subtotal	9	$ 4,757,855	$ 528,651
D. Preventable by Pilot Restriction:			
Fatal	2	$ 1,228,132	$ 614,066
Serious Injury	3	201,827	67,274
Minor Injury	3	70,569	23,523
Property Damage Only	0	0	0
Subtotal	8	$ 1,500,523	$ 187,565

Distribution of Costs. This table provides a rapid overview of the distribution of accident costs. The mismanagement of fuel group is roughly four times the improper operation of powerplant and powerplant controls group. Note also that the mismanagement of fuel group has a higher average cost. This can be traced to the higher incidence of fatal accidents in the mismanagement of fuel group as compared to the improper operation of powerplant and powerplant controls group. The number of aircraft occupants is a strong variable in the final cost result. Note on Table 27 that one accident with four fatalities accounted for half the cost of the powerplant and powerplant controls group, preventable by standardization.

POTENTIAL ACCIDENT COST REDUCTION.

The two major data items from the preceding work which drive the future cost reductions are the fractions of accidents which are preventable and the average cost of the individual accidents. With these values it becomes possible to derive the costs of all accidents for a typical year. A further extrapolation is then required to predict the number of accidents in the future years. The objective in this section is to determine savings at the fifth and tenth years after the incorporation of cockpit standardization.

THE ANNUAL LOSS DUE TO PREVENTABLE ACCIDENTS. The results apply only to accidents related to the cockpit standardization problem. The starting point is the full NTSB data base of 2,011 accidents due to both primary causes. A stratification of the accidents was previously presented in Table 1. From that table, the five-year totals for all accidents is extracted, by level of severity. This is the left-hand column of Table 30, and the average number of accidents per year is immediately adjacent.

TABLE 30. ANNUAL LOSSES DUE TO PREVENTABLE ACCIDENTS

Accident Severity	5-Yr Total	Av. Per Year	Fraction Preventable	Annual Pvtbl Acc.	Av. per Accident	Total Cost
Fatal	174	34.8	0.172	5.98	$900,200	$5,383,000
Serious	275	55.0	0.238	13.10	60,900	798,000
Minor	451	90.2	0.233	21.10	21,400	452,000
Prop. Dmg. Only	1111	222.2	0.034	7.55	9,040	68,000
	2011	Total for all Levels				$6,701,000

The fraction of these accidents which is preventable by standardization is a crucial quantity. A previous table has shown the number of accidents in the selected sample by level of accident severity to be:

Fatal injury accidents	-	99
Serious injury accidents	-	42
Minor injury accidents	-	30
Property damage only accidents	-	29

The accidents which are preventable by cockpit standardization are also extracted from a previous table where the quantities are:

Fatal injury accidents	-	17
Serious injury accidents	-	10
Minor injury accidents	-	7
Property damage only accidents	-	1

The ratios are shown in the third column of Table 30.

The next steps produce the cost values. The number of preventable accidents is the product of the average per year times the fraction preventable. Then, with average accident costs from Table 30, the totals for all severity levels are computed in the right hand column. The sum total is $6,701,000.

A clarification is in order at this point. The costing of the previous section was done for the countermeasures data base, i.e., the preventable accidents. The totals shown in Tables 25 through 28 are large by comparison with the results of Table 30, even though the latter table applies to the full NTSB data base. This comes about for the following reasons. The sample data base contains a much greater proportion of fatal and serious accidents than does the full NTSB data base due to the optimum sampling allocation process. As a consequence, the average accident costs shown in Table 29 have better accuracy than if a proportional sample had been taken. But, the full NTSB data base shows only 35 fatal accidents for an average year of which only six are rated as preventable. The fraction preventable and average cost per accident are the key results from the detailed study of the sample accidents and, when applied to the full NTSB data base yield, with the best possible accuracy, the results of Table 30.

THE PHASE-IN OF STANDARDIZATION. Given a mandatory requirement to commence standardization in general aviation cockpits, and some future date for full compliance, an estimate is required of the implementation schedule.

Some assumptions are required. The manufacturers would undoubtedly proceed on engineering change orders with existing staff. As design revisions become available, there needs to be planning for the changes in production processes. Finally, the orders for new materials and parts and the modified production would take place. The total time required is estimated at six months. Depending on the work load at the plant, a major producer might cope with modifications of two or three models at a time. The major manufacturers have distinct models numbering in the range of 10 to 20. Following this line of reasoning, it is expected that a period of five years would be required before all new production conformed to the standardization guidelines. It will therefore be estimated that over each of the five years, the new production will appear in 20 percent increments.

Shipment Quantities in the Projected Period. The term shipment quantities, as used here, should be understood to include only those aircraft going into the domestic general aviation fleet and will not match the industry shipment data which includes export quantities. Again, some estimates are required to proceed with the determination. The size of the general aviation fleet has been forecast out to 1993 in a recent FAA report (Reference 16) dated February 1982. These data show the depressed state of the industry over the recent past where it can be noted that the fleet increase in 1981 was a mere 0.7 thousand units compared to the previous year's increase of 11.5 thousand units. It is interesting to observe in the data that forecast values can be both high and low and that over a period of years the forecasting errors tend to cancel one another. For example, the fleet size for 1980, as shown in the reference at 210.3 thousand units, had been forecast only two years previously at 208.6 thousand units. Otherwise stated, the forecast fleet size was 1.7 thousand units under the actual just prior to the severely depressed year of 1981 where the forecast fleet size was grossly over the actual.

Using 1983 as the year during which new design aircraft might commence the phase-in process, deliveries to the domestic fleet can be estimated. Annual deliveries will cover the increase of the fleet plus the losses to attrition/scrappage. An established estimate on the average life of a general aviation aircraft is 18 years. Examination of fleet increments in the mid-sixties shows substantial deliveries were on the order of 7,000 units annually. However, the use of an average life value is complicated by the possible tendency of owners to postpone aircraft replacement during economically depressed periods. In the interest of a conservative estimate on aircraft shipments, the value of 25 percent above the fleet increase increment will be used to account for attrition. This level will depress the rate of replacement deliveries during poor years and increase them during years of high production, but will still not provide for full replacement on the basis of an 18-year average life, since the life itself may be in a process of growing.

Shipments of Modified Designs. The terms modified design and new design are used interchangeably. Our concern is only that the standardization features be incorporated in newly produced aircraft either as changes in design of existing models or by the introduction of new models. It is now possible to combine the two trends developed above, i.e., (1) introduction of new designs, and (2) forecast shipments. This will lead to the values for new design shipments and the total of new design aircraft in the fleet. The development of the quantities is contained in Table 31. An interesting observation in the table is that the buildup of modified design aircraft, as shown in the right-hand column, commences very slowly. This is due to the low deliveries forecast for the early years of the 10-year period under study and the very gradual rate at which the design modifications are estimated to be introduced. However, it is also apparent that the buildup will accelerate, and, that by the end of the tenth year, the modified design aircraft constitute more than one-third of the active fleet.

TABLE 31. QUANTITIES OF MODIFIED DESIGN AIRCRAFT
(All in Thousand Units)

Time	Forecast* Fleet	Shipments** To Fleet	Shipments New Design	New Design Cumulative
First year	218.1	5.1	1.0	1.0
Second year	223.9	7.2	2.9	3.9
Third year	231.9	10.0	6.0	9.9
Fourth year	242.4	13.1	10.4	20.3
Fifth year	253.9	14.4	14.4	34.7
Sixth year	265.8	14.9	14.9	49.6
Seventh year	278.4	15.7	15.7	65.3
Eighth year	291.9	16.8	16.8	82.1
Ninth year	305.9	17.5	17.5	99.6
Tenth year	319.5	17.0	17.0	116.6

* Source: FAA - February 1982. Based on 1982 start.
**Includes increments of fleet increase plus replacements

PROJECTED COST SAVINGS. It should be emphasized at the outset of the cost determination that no retrofit of cockpit standardization features is contemplated and that the only source of cost saving is the introduction of new aircraft to the active fleet. The annual loss due to preventable accidents was developed in Table 30 and found to be $6,701,000. Table 31 shows the introduction of new aircraft with accident suppressing features. The projected cost savings derive from the presence in the general aviation fleet of these aircraft. Therefore, in Table 32, the first significant quantity is the new-design fraction, representing the proportion of new aircraft to the fleet size. The annual cost reduction is the product of this fraction times the annual loss due to preventable accidents.

As would be expected from the rate at which new design is introduced, the initial cost reductions are not significant. Table 32 shows, however, that the annual cost reductions do mount substantially after a few years. The right hand column shows the cumulative values which surpass $11 million after 10 years. Note also that the second $11 million should accrue after only four additional years. In this period, the new design fraction will be climbing over 0.40. At the fourteenth year, more than half the fleet will contain the new designs.

TABLE 32. PROJECTED COST REDUCTIONS
ACCIDENT PREVENTION BY COCKPIT STANDARDIZATION

Time	Forecast* Fleet	New Design Fraction	Ann. Cost Reduction	Cum. Cost Reduction
First year	218.1	0.005	$ 33,500	$ 32,500
Second year	223.9	0.017	113,900	147,400
Third year	231.9	0.043	288,100	435,500
Fourth year	242.4	0.084	562,900	998,400
Fifth year	253.9	0.137	918,000	1,916,400
Sixth year	265.8	0.187	1,253,100	3,169,500
Seventh year	278.4	0.235	1,574,700	4,744,200
Eighth year	291.9	0.281	1,883,000	6,627,200
Ninth year	305.9	0.326	2,184,500	8,811,700
Tenth year	319.5	0.365	2,445,900	11,257,600

* Source: FAA - February 1982. Based on 1982 start.

To fully assess the importance of these economic benefits, it would be required to proceed to the analysis of costs for implementation of the standardization. At this time, the specific features of new design are not established and this study has proceeded with standardization guidelines only. A comparison on the basis of standardization costs was not included in the scope of this work.

INFLUENCE OF SAFETY ON GENERAL AVIATION ACTIVITY.

There is, in addition to the primary objective of this investigation, a lesser effort to find additional benefits to the accident reduction accruing from cockpit standardization. It might be expected that flying activity would increase as general aviation accidents became fewer. If the long term data are examined, this does appear to be the case. However, as the data are examined over shorter periods, and the year to year variations are observed, there is no discernible impact of the number of accidents on aircraft sales. Obviously there are many economic factors governing sales and new pilot starts as well.

THE LONG TERM TRENDS. The trends in general aviation activity show steady favorable growth over an extended period of time. The twenty-five year period from 1955 to 1980 is covered in the plots of Figure 9. In that period of time, the size of the fleet increased by a factor of 3.4. Note in the figure that the increase in the size of the fleet is quite steady. There is a slight increase in the rate of expansion in the late 1960's and a slight contraction in the early 1970's, but these hardly alter the form of the growth curve.

Fleet Size and Unit Shipments. Several factors bear on the size of the fleet. In the few years immediately following World War II, production of general aviation aircraft was at an unsustainably high rate. Shipments totaled 50,000 units in two years. While some of these were for export markets, the remainder provided a strong nucleus for the domestic fleet. The post-war period was one of strong growth in the overall economy and general aviation shared in the prosperity.

There are other possible contributors to the increasing size of the general aviation fleet. The popularity of flying as an avocation is one. Note the curve on the figure showing flying activity as measured by annual flight hours. In particular, while this curve progresses up with a consistently rising rate over 20 years, there is a nearly step-like increase in 1965. This precedes the steepening in the fleet-size curve and may have been a precursor of even higher interest in flying. Additionally, the evolution of new designs by the manufacturers may stimulate purchase.

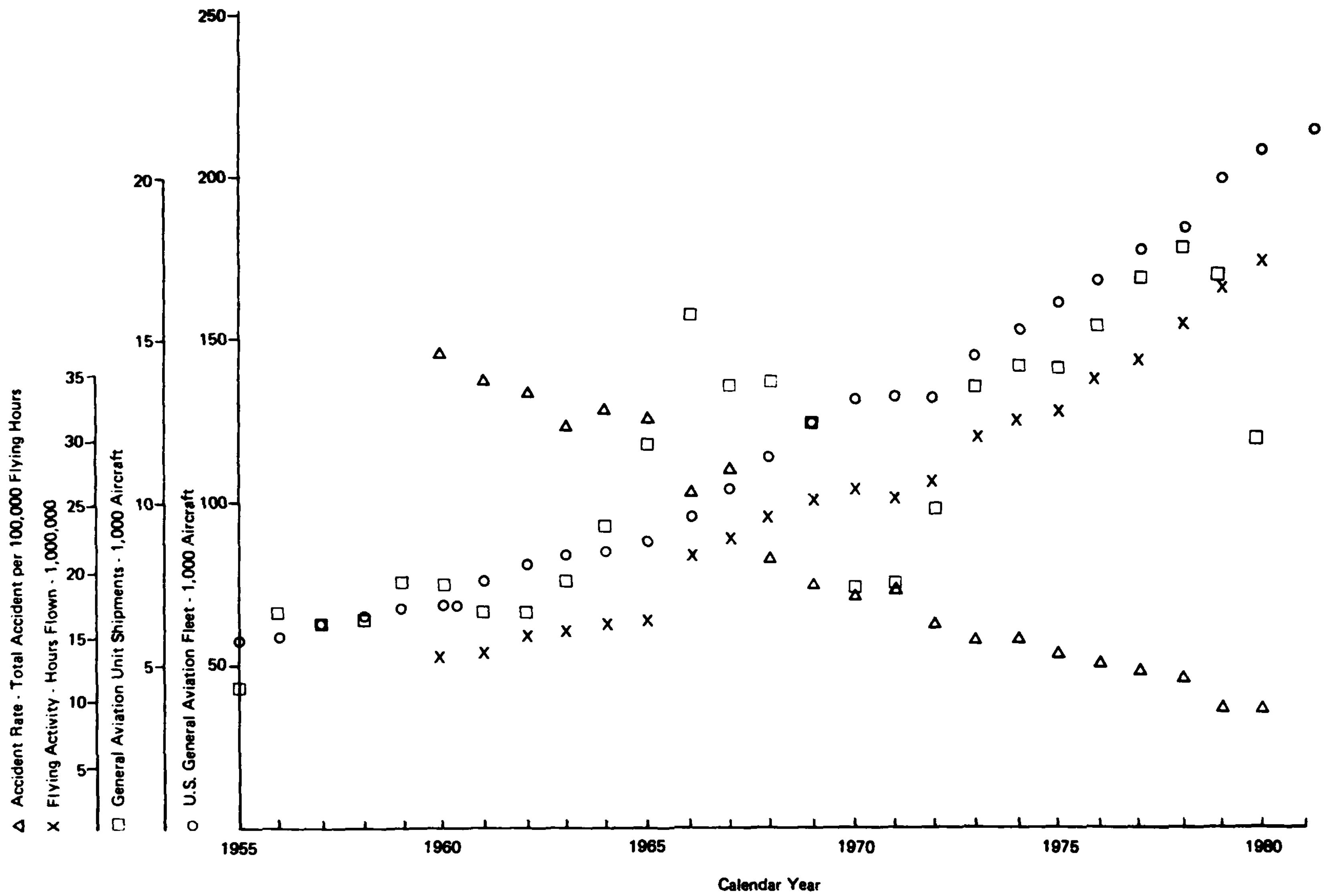


FIGURE 9 TRENDS OF GENERAL AVIATION ACTIVITY

The unit shipments of the industry are also shown in the figure. The overall form of the curve matches the upward trend in fleet size and flying activity but with a yearly variance much greater than seen in either. The FAA has noted (Reference 17) that the industry is characterized by a high degree of volatility due in part to its sensitivity to general economic conditions, and to prospective purchasers' anticipation of future price trends. It can be seen that the high production years of 1965-69 were followed by weakness in the years 1970-71. The sharp jump in deliveries for the few years in the mid-sixties may be traced to the high post-war production and known mean life of general aviation aircraft of 18 years. However, recovery after the low years was rather prompt and the long term trend was quickly reestablished. Note also that the general economic weakness around 1974 does appear to have influenced shipments of aircraft. It would appear that the manufacturing activity in this industry has a complex relationship with the overall economy, perhaps reflecting a special character in the user group, the private pilots.

The Trend in Safety. The accident rate is included in Figure 10 where the commonly used quantity of accidents per 100,000 flying hours is plotted. The decrease over twenty years is from about 36 to just under 10. This ratio is approximately matched by the rate of increase in flying hours over the same period. Thus, the absolute number of accidents is not coming down even though the safety must be regarded as markedly improving. The curve shows a consistent trend downward with only a nominal upward perturbation about 1964-65. Since this period immediately preceded the high volume production period, the probability of a correlation is weakened. Conversely, it can be argued that the improving safety record is one element in the total environment that has fostered the high, and increasing, level of general aviation activity.

BENEFIT CORRELATION WITH ACCIDENT PREVENTION. To further explore whether accident prevention might influence the production of aircraft and new pilot starts, several statistical tests were applied to data for the period 1970-80.

The Accident Rate. The accident rate displays a strong and continuing decrease with time, with only minor deviations. Curve fitting was applied to the data points using a decaying exponential. The curve was imposed at integral values of the accident rate at 1970 and 1980 using 18 and 10 respectively (per 100,000 hours of flight). The exponential term is found to be - 0.588x, where x is the number of years after 1970, and the curve is sketched in Figure 10. The 1990 value is calculated to be 5.56. The standard deviation is 0.67 which indicates a better fit might have been possible but that the form of the curve is valid. The relatively small standard deviation indicates also that extrapolation to future years should be possible without an excessively large contingency range. Of course, the coefficient of the exponential term needs to be recomputed for the lower accident rates associated with cockpit standardization but there is no way to proceed on that step without the correlation between accident rates and the dependent parameters.

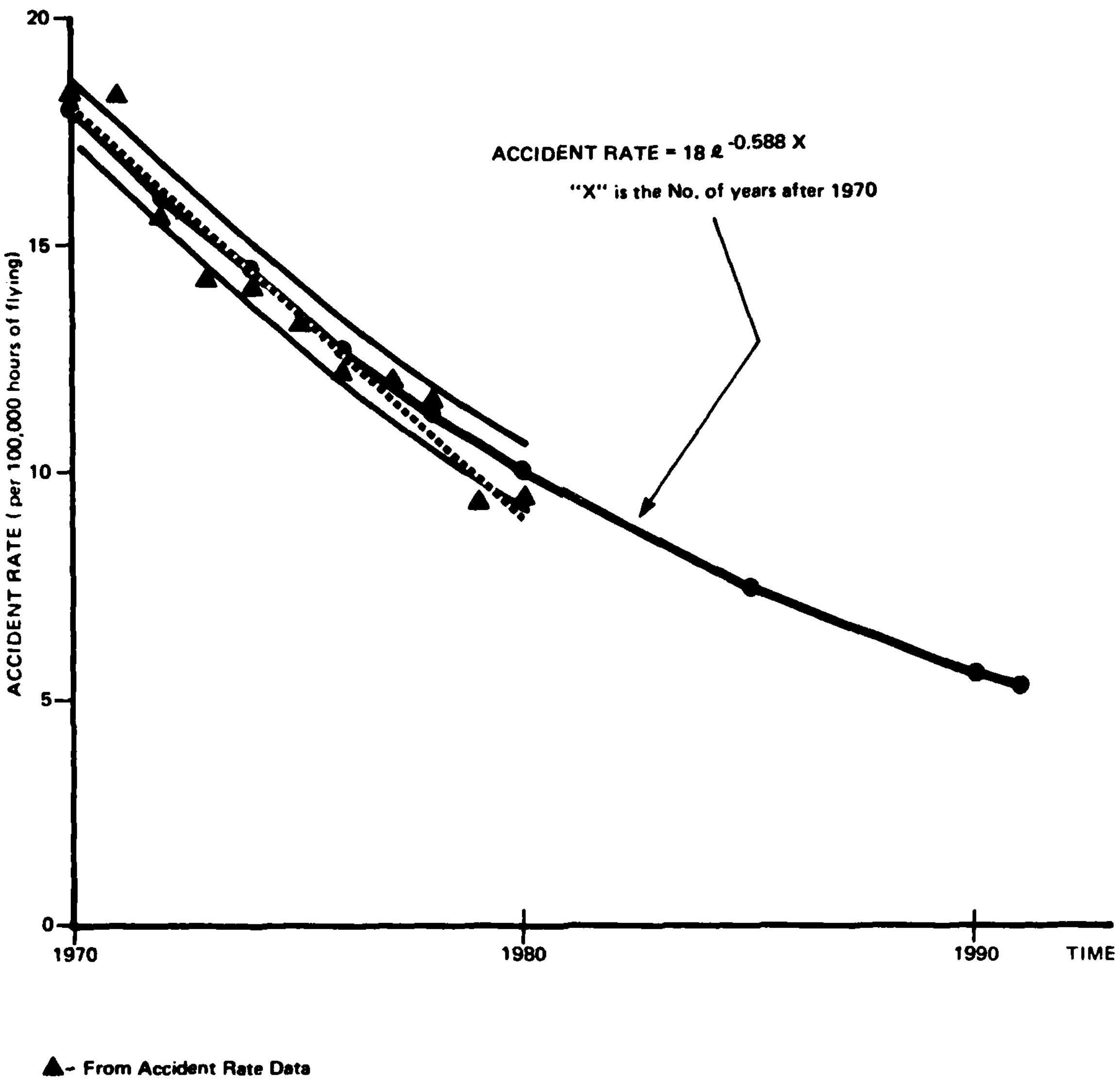


FIGURE 10. ACCIDENT RATE CURVE FIT

The Aircraft Production Rate. The number of units shipped, in sharp contrast to the accident rate, does not present a consistent pattern with time. The first check has been the fitting of a best straight line using both the periods 1970-79 and 1970-81, the data for which are in Figure 9. The slope of the curve for the first period shows a value twice as steep as for the second period. Results for the first period were found to be: a mean of 13,372 units per year with a standard deviation of 3,868 units, and a slope of 1,213 units per year. For the slightly longer period, including 1980-81, the results were found to be: a mean of 12,921 units per year with a standard deviation of 3,690 units (with five data points outside the standard deviation), and a slope of 502 units per year. In view of this erratic production rate behavior over the same period that the accident rate is relatively predictable, it must be concluded that no correlation exists. Figure 11 graphically shows the independence of the two functions where, for several time periods, the two curves move in the same direction which is certainly not to be expected. For example, in the late 1970's, the shipment quantities head sharply downward while the accident curve maintains its usual downward tendency. Another plot of the data, also contained in Figure 11, uses the number of aircraft shipped in the years following those for the accident rates. This shifting does not yield any change in the absence of a relationship of the two functions.

New Pilot Starts. New pilot starts are found to be nearly independent of time with a substantial year to year variation. The mean value is 125,901 starts annually. A best straight line curve fit has a slope of -424 starts per year. While this is a very minor slope, it is negative and thus does not show an increasing number of new pilot starts during a period of improving safety performance. For the best curve fit, the standard deviation is 10,407 starts annually with five points outside the plus or minus band. Replotting the data so that new pilot starts are aligned one year behind the accident rate values does not change the situation. There is no apparent relationship between accident rates and new pilot starts from examination of the two sets of data. Figure 12 contains new pilots starts plotted against both total accidents and the accident rate. In the plots of new pilot starts and accidents, the prevalence of opposite slopes for several short periods is clearly apparent. The second set of plots shows randomness in new pilot starts when compared to the steady improvement in the accident rate.

Statistical Correlations. Correlation analysis is another avenue for measuring the relationship between variables. This technique was applied to the problem of determining the dependence of aircraft shipments and new pilot starts on general aviation safety. The main results are found to be these values of coefficient of correlation (r):

1. Aircraft shipments versus accident rate, 1972-79
   $r = -0.896$
2. Aircraft shipments versus accident rate, 1970-80
   $r = +0.299$
3. Aircraft shipments versus prior year accident rate, 1972-79
   $r = -0.104$
4. Aircraft shipments versus number of accidents, 1972-79
   $r = +0.316$
5. Aircraft shipments versus prior year number of accidents, 1972-79
   $r = +0.483$

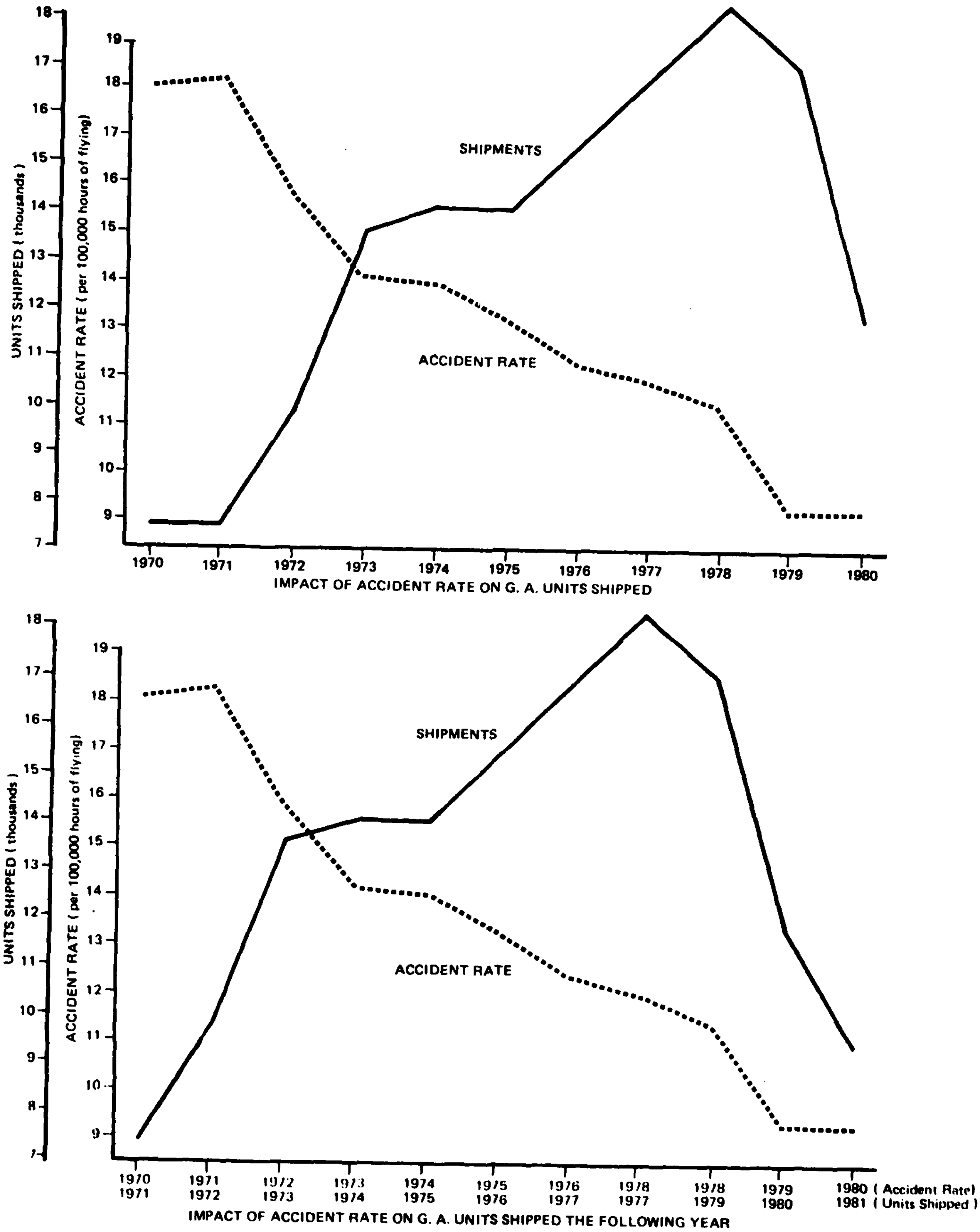
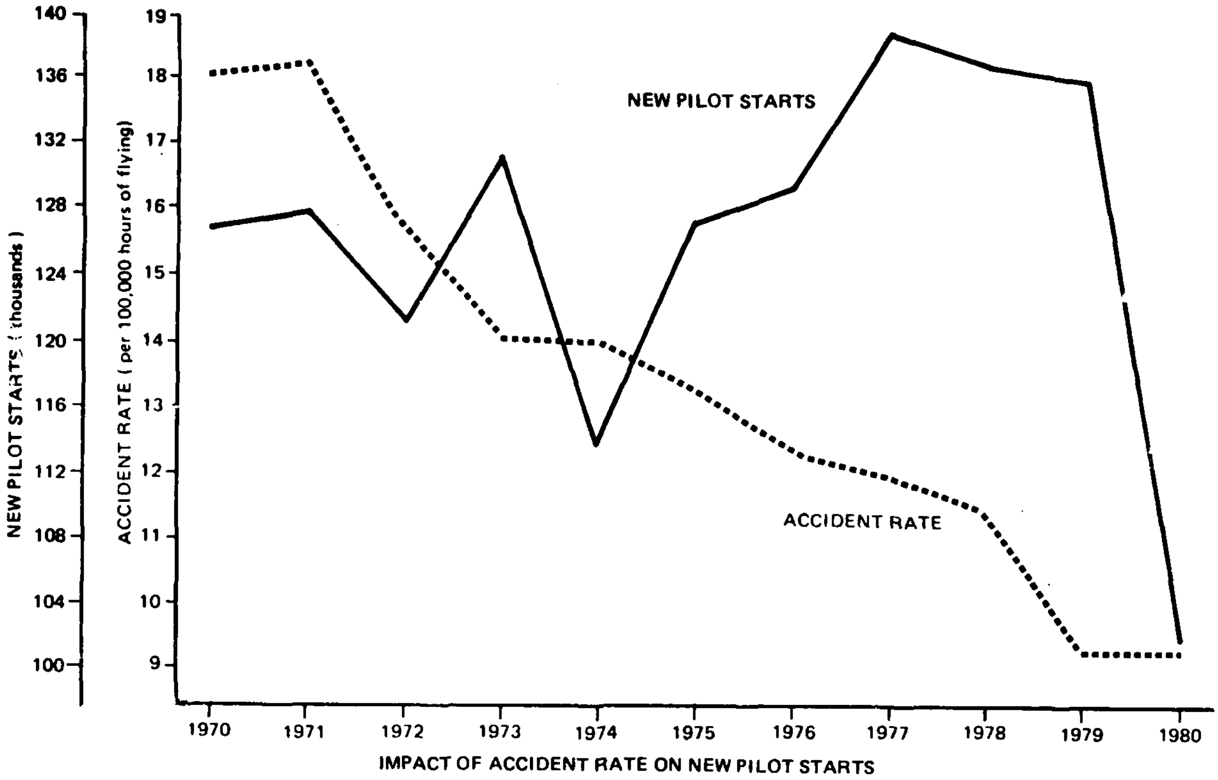


FIGURE 11. AIRCRAFT SHIPMENT - SAFETY RELATIONSHIP



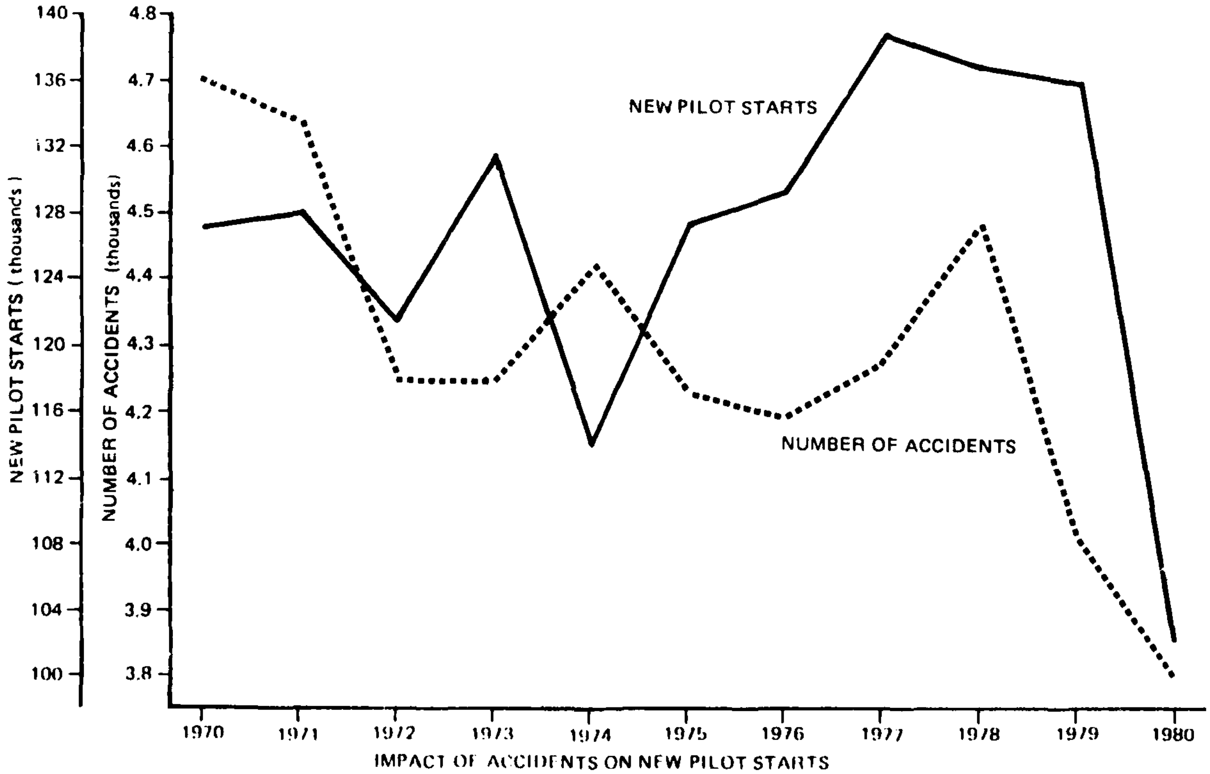


FIGURE 12. NEW PILOT STARTS AND SAFETY

6. Student licenses versus accident rate, 1972-79
   $r = -0.880$
7. Student licenses versus accident rate, 1970-80
   $r = -0.561$
8. Student licenses versus number of accidents, 1972-79
   $r = -0.161$

Observation of the coefficient values shows them generally at low levels so that no cause and effect relation can be established. The single value that might have pointed to a correlation is that for aircraft shipments versus accident rate over the period 1972-79 where the coefficient is found to be -0.896 which is statistically significant at the one percent confidence level. Note, however, that if the time period is extended to 1970-80, merely three additional years, the coefficient drops to 0.299 and the sign changes from minus to plus. Obviously, the downturn in shipments in the late 1970's invalidates any finding that a true correlation exists.

A further analysis was performed to include the effect of the real Gross National Product (GNP). The correlation coefficient for aircraft shipments against the real GNP was found to be:

$r = 0.880$ for 1972-79
$r = 0.9997$ for 1970-80

These "r" values, taken together, provide a strong correlation between aircraft shipments and real GNP. There appears to be only a small probability that safety improvements or any factors other than the state of the economy influence aircraft shipments over the long term. For student licenses, a similar result was found, as the coefficient shows:

$r = 0.959$ for 1972-79

Thus, the student license numbers are also influenced more by the economy than by other factors such as safety.

PROPOSED MEASURES FOR IMPROVED COCKPIT FAMILIARITY.

While the primary emphasis throughout this study has been on standardization as a means of improving pilot familiarity with the cockpit arrangement, additional consideration was given to pilot restrictions. A rating system was formulated earlier in this report for assessing accidents as being preventable by pilot restrictions. The rating was based on a composite of pilot qualifications and experience although there are several areas of pilot lack of experience and recency of experience which are of interest. This obviously complicates the problem of implementing pilot restrictions as a step in accident limitation. Consequently, an approach is proposed here that has promise of assuring satisfactory familiarization of the pilot with the cockpit environment with emphasis on fuel system management and powerplant control operations.

PILOT QUALIFICATIONS AND EXPERIENCE. The fact shows clearly in the data that pilots may be well qualified and highly experienced but still be involved in pilot error type of accidents that appear, on an analytic level, to be preventable. Even though some, or even most, of the accidents have some degree of a design-induced character, pilot qualifications are examined here to find the kind of restrictions that might be effective in accident reduction.

Type of Certificate. The most striking fact has been the substantial number of advanced certificates held by pilots of the accident group. While private pilots constitute about half the total, commercial pilots are just over one-quarter the total. Commercial and airline transport flight instructors are included at 11.0 percent and 2.0 percent respectively, not insignificant levels for these advanced certificates. Student pilots as a group comprise only 8.3 percent of the accident cases.

The written and flight tests for the private pilot certificate include many topics which are related to aircraft accidents such as:

- Use of airman information manual.
- VFR navigation.
- Recognition of critical weather.
- Collision avoidance.
- Flight at critically slow airspeeds and recovery from stalls.
- Maneuvering by reference to instruments.
- Cross-country flying and the implied management of a fixed fuel quantity.
- Night flying including VFR navigation.
- Emergency operations including simulated malfunctions.

The requirements for a commercial certificate add several items which are related to the accidents of the sample. Competence in emergency procedures explicitly includes power loss. Controls include those of more complex aircraft designs such as controllable pitch propellers and retractable landing gear. The cross-country flight requirements are difficult enough to establish a fuel management capability well beyond that assured by a private pilot certificate. The commercial pilot certificate implies that an instrument rating is held but does not assure the instrument rating since an endorsement may be applied showing the lack thereof.

Basic flying skills and qualifications are assured by the certificates at several graduated levels but the question of transferring these skills from one airplane make to another is avoided. It would appear to be an administrative impossibility to impose on FAA pilot certification the task of endorsing certificates for specific airplane makes and models. Furthermore, the process of a pilot moving from one model to another would be slow and tedious and general aviation activity might be needlessly dampened. In short, the accident pilots are not lacking in representation of advanced certificates so this aspect of their qualification does not appear to be a strong variable in the approach to accident prevention. Conversely, there would be substantial adverse consequences in using pilot certificates to implement pilot familiarity with cockpit arrangements.

A similar finding appears in a study by the NTSB pertaining to engine failure accidents in light twin-engine aircraft (Reference 9). In that work, a rather small number of cases were examined in great detail. More than half the pilots had over 2,000 hours of flying time. It would be expected that pilots of twin-engine aircraft as a group would be more experienced than the total for all general aviation but the report emphasized that the accident group as a whole is highly experienced, has substantial time in type, and holds advanced level certificates.

Total Flight Time. The situation in total flight time parallels that in type of certificate. The accident pilots as a group, on average, are experienced. Restrictions in this regard would be similar to those in type of certificate. That is to say that the penalties would probably be a great burden and the hoped for accident reduction would not be assured.

Hours in Type. The time of the pilot in a specific make and model is measured by this quantity and therefore is the most related to cockpit familiarity. On this basis, the largest group of the accident pilots had 100-300 hours which is substantial experience.

On an overall view, the time in type experience is not found to be deficient. Therefore, the prior remarks about the administrative burden of endorsing certificates with additional data items and the questionable benefits make this approach less than ideal. If a pilot log is used to establish the experience of the pilot in type aircraft, and a mandatory threshold is set by the FAA at a level above 40 hours, then a private pilot certificate could be invalidated. Lesser time periods would tend to minimize the importance of time in type. In any case, the number of hours in type is not an absolute indicator that the pilot has the necessary familiarity to react correctly in all emergency situations.

Recency of Experience. This quantity is difficult to measure but a picture of the accident pilots indicates that no definite deficiency exists here. There is some precedent for considering the flying time of a pilot in the just-past 60-day period. For example, Par. 61.107 (Reference 18) on flight proficiency of private pilots requires that the preparatory flights prior to the test flight will have been performed within the prior 60-day period. Some fixed base operators use a 60-day period in screening applicants for rental aircraft. However, the useage in this report has been on a 90-day period since the NTSB files contain that number as it appears on the accident report. Some of the reports contain flying hours for the recent period that appear to be in error and in other cases are blank.

Instrument Time. This attribute of pilot qualification and experience influences the accident causes and additional factors in an indirect way. The case studies uncovered instances where flights under VFR encountered heavy weather, diverting the attention of the pilot from aircraft operation or producing spontaneous and improper actions resulting in mismanagement of fuel and/or improper use of powerplant controls. Of the pilots in the 200 accident sample, one-third hold certificates with instrument ratings. Additionally, others have some instrument time even though it is not rated. As a group these pilots have qualifications in instrument flying.

As for the 47 countermeasure accidents, instrument rated pilots within the mismanagement of fuel category totaled five out of a possible 35 (13.9 percent). Similarly, within the misuse of powerplant and powerplant control category, instrument rated pilots are only one out of a possible 12 (8.3 percent). These figures indicate that the countermeasure pilots are not instrument rated at the same proportion but, in fact, much less.

PROPOSED FAMILIARIZATION EXAMINATION. The crux of the problem is that despite the unquestionable qualifications of the accident pilot group as a whole, the inability to cope with non-standard cockpit arrangements underlies the causes of many accidents. The rating measures used in this investigation, despite the limitations of precision, show that 23 percent of the accidents would have been prevented by cockpit standardization or by pilot restrictions. The first of these two kinds of measures will produce benefits only gradually as the new designs enter the active general aviation fleet. This leaves the pilot option as the one that could produce more immediate results. Mandatory restrictions have limitations as compiled earlier in this section. Therefore, an approach is proposed which gets directly at the cockpit familiarity problem and could be implemented without administrative burdens.

The FAA program for accident prevention in general aviation includes publications on safety procedures and techniques. While these publications appear to be advisory in nature, the fact of their approval and distribution by FAA enhances their acceptance by the fixed base operator (FBO) and pilot communities.

The Base Operator Problem. The decision on whether a certificated pilot may rent or lease a particular make/model aircraft rests on the FBO. He may have insurance company requirements as guidance on rental pilot qualifications. Also, he will be generally motivated to maintain safe conditions at the airport. Despite these observations, there is evidence of great variability among fixed base operators in the matter of qualifying a candidate for aircraft rental. The accident analysis pointed up some instances of lax practice and a brief survey in one metropolitan area confirms a variability among operators.

An Example from Accident Analysis. A cogent example is found in Accident Case No. 3-2445. The pilot's credentials were in order. He was put through a cursory check flight. The NTSB investigator found that the prospective renter had satisfactorily performed a takeoff, some elementary maneuvers, and a landing. He was briefed on traffic regulations of the airport and restricted military areas. There was little or no coverage during the preflight briefing on the arrangement of cockpit controls. In particular, the pilot was not informed about the necessity to read all fuel tank quantities on a single gauge nor on the switching of the gauge.

The FBO Survey. This was conducted at a limited number of fields in the Washington metropolitan area. Two operators stand out as enforcing rigid requirements for rental pilot qualifications. Both of them examine certificates, log books, medical records, and radio operators' licenses. Both require a check flight regardless of the flight time of a pilot and his time in type for first time renters. Subsequent rentals do not require a check flight if the period between flights is 60 days or less, in one case, and 30 days or less in the other. These operators regard their check flights as demanding enough to firmly establish the competence of the pilot in the make/model to be rented.

One of these two operators presently uses a written examination prior to the check flight (see Appendix B). While the examination forces the applicant to be aware of the principal performance characteristics of the aircraft to be rented, it does not cover cockpit familiarization at all. The critical speed values are called for, there are some useful load and weight/balance questions, and, to a limited extent, there are questions on fuel tanks and quantities.

The other of the two standout operators uses an intensive oral test prior to the check flight. Coverage is similar to the above with emphasis on takeoff and climb, the critical design speeds, and includes some questions on the fuel system. The initial flight test covers a full hour.

The survey of FBOs included a sounding out of their reaction to a written examination prepared by the FAA. The response was favorable. Those operators who apply strict requirements are quite enthusiastic since they continually face a loss of clientele to the more lax fields. A written examination, if issued by FAA, would promote more nearly uniform standards at all fields and would thus work to equalize the competitive positions. Those FBOs who are less restrictive can see the opportunity to improve their safety precautions with a minimum of effort on their own part.

Use of the Familiarization Examination. The examination would be a preprinted, written exam to establish that the pilot is familiar with the cockpit arrangements of the aircraft make and model he intended to fly. Additional questions could be included on the performance characteristics of the particular aircraft to be rented or leased. There might also be some questions intended to improve preflight inspections. Answers to questions would be required in sufficient detail to prevent the possibility of a guess. The use of the pilot handbook would be required for finding some of the answers. Other questions would require the pilot to carefully examine the cockpit and to lay hands on the controls in order to find the answers. One examination form would be applicable to all makes/models but of course the answers would be peculiar to each.

The intent of the examination would not be to disqualify pilots from renting aircraft but rather to provide the necessary learning experience in cockpit arrangements. The written examination would promptly disclose inadequacies in the pilot's mastery of the airplane. The written examination is no substitute for a check flight but rather shows the weaknesses that might be correctable during the check flight. Conceivably the performance of a pilot on a written examination might be poor enough to cause an immediate disqualification to operate a particular model of aircraft.

Finally, the written examination provides the base operator with a permanent record. This might be useful for insurance purposes. It could also be available for accident investigations.

Typical Content of the Examination. All the critical instruments and controls should be covered by the examination with emphasis on the areas where lack of standardization has been found. The examination might also be directed at areas where pilot handbooks are known to be unclear. As a minimum, coverage should extend over all actuators and instruments involved in accidents.

One known problem provides an example. For pilots not accustomed to the matter of switching fuel quantity indicators, a capability could be established by questions along these lines:

1. State the number of fuel tanks and their locations.

2. State the number of fuel quantity gauges and their locations.

3. If switching of gauges is required, state the length of time for the reading to stabilize after switching.

4. If the number of gauges is less than the number of tanks, and the gauges do not have a switch, describe how the gauges can be made to read each tank quantity.

5. State what relationship, if any, there is between the positioning of the fuel selector valve and the link between fuel quantity gauges and fuel tanks.

6. Determine the fuel quantity in each tank by reading each gauge and switching where necessary, and then observe the fuel in each tank and state the accuracy of each gauge.

Note that if the answers to 1 and 2 are different, the pilot is impressed with the need to switch gauges to read all tanks. He could be using both the handbook and cockpit to answer the questions. Item 3, however, requires actual manipulation of the switch in order to get the answer. The question also alerts the pilot to the possibility of getting an erroneous reading on the quantity gauge unless due care is exercised, even when the gauge is functioning properly.

Another problem area is the use of carburetor heating. Some of the flight manuals provide little or no guidance to the effective use of carburetor heating. Questions along these lines would establish a level of experience with the airplane design or provide the check pilot with an opportunity to clarify an indicated deficiency:

1. State the location of the carburetor heater handle or knob.

2. What warnings, or instruments, are available to the pilot that carburetor heating should be applied?

3. Under what conditions should carburetor heat be applied at partial or maximum settings?

4. If carburetor heat is applied during a normal landing, what resetting, if any, is required if the landing attempt is aborted?

5. What length of time is normally required for carburetor heat to clear an iced condition?

These questions will require the pilot to search the manual. He will certainly be alerted to the need for correct application of carburetor heat. Additionally, if he answers these questions on the basis of experience on one make/model and the characteristics of another require different answers, the check pilot or examiner will have the chance to clarify the correct procedures.

A blindfold exercise could be incorporated into the cockpit familiarization examination. The case analyses of accidents disclosed a number of examples where the pilot kept a visual focus on the external situation and operated fuel system or powerplant controls by feel only, and committed errors in the process. The benefits of the blindfold technique are appreciated in some quarters, but a more widespread use would promote correct response of pilots to emergencies.

Application of the Familiarization Examination. This proposed examination is suggested as being suitable for implementation on an advisory basis. There is some motivation for its use by base operators. In the event that there is substantial but incomplete acceptance of the measure, its results could be determined. Assuming that some benefits are observable, then consideration could be given to mandatory application. Alternatively, if the benefits that accrue to the voluntary use of the examination are deemed adequate, there may be no need for its mandatory use.

FINDINGS AND CONCLUSIONS

The findings presented below extend over the full scope of the investigation. The detailed analysis of accidents was performed for a five-year period where primary causal factors have been assigned as pilot error involving fuel management and powerplant controls, with additional specified causal factors linked to the primary ones. Beyond those, weather and preflight inspections turned up as causal factors and added an additional dimension of insight to accident causes. The potential benefits to be realized by cockpit standardization, or in a broader-sense, optimization, are found from the analysis of accidents and the subsequent cost determinations. The possibility of pilot restrictions is considered as a means of assuring that cockpit familiarization is enforced.

ACCIDENT ANALYSIS FINDINGS.

FORMATION OF THE ACCIDENT DATA BASE. The sampling technique proved satisfactory and provided a collection of accidents, about one-tenth the size of the NTSB full data base. With 200 accidents the working data base was feasible for detailed examination. A satisfactory diversity in accident environments, pilot experience aircraft make/model mix, and the like was obtained. An optimal allocation of variance in sampling directed that a larger than proportional number of fatal and severe accidents be included in the sample to assure the best accuracy in the cost determinations.

MISMANAGEMENT OF FUEL AS AN ACCIDENT CAUSE. General aviation fuel systems contain deficiencies which contribute to design-induced pilot errors. The accident analyses confirm that location, manipulation, and interpretation difficulties are involved in the accidents. An examination of cockpit arrangements of all aircraft in the accident sample further confirms that diversity is extreme and that the lack of standardization is not connected to the accidents by chance. Fuel system problems dominated in the accident sample by a two to one ratio over powerplant control problems. Fuel selectors are in many different locations and some do not provide convenient access. Operation of the fuel selectors differs markedly over the range of aircraft designs. Fuel gauges are often confusing to interpret, especially when not related to tank or selector positions. Reliability of fuel gauge accuracy is not satisfactory. Most aircraft do not have a console alert as to which tank is in use. Auxiliary fuel pump switches are not position coordinated with respect to other controls, and in some designs, are difficult to use and do not have clear owner manual instructions. In crisis situations, fuel controls are often manipulated by feel and not by sight.

IMPROPER POWERPLANT OPERATION AS AN ACCIDENT CAUSE. Many of the powerplant control accidents in the sample were recorded as carburetor icing problems. The need for carburetor heat is difficult to determine, even for pilots with substantial experience. The effective application of carburetor heat, both in duration and intensity, is difficult to determine. Pilot handbooks and operator manuals are vague and confusing on the application of carburetor heat. Other manuals are very limited in their discussion of icing problems and remedies. Engine restart procedures are not well defined in manuals, particularly in the case where one tank has been drained and a tank change is required. The finite time to reestablish fuel flow is omitted in manuals and, as a consequence, many pilots have been found to switch tanks back and forth in an emergency and thereby reduced their chance for a restart. Position coordination of engine controls is inadequate for many pilots as they attempt to cope with emergency situations. Friction locks on some powerplant controls are difficult to release in some emergencies.

RELATED CAUSAL FACTORS IN ACCIDENTS. The most frequent of additional causal factors in the sample accidents involves in-flight decisions and planning. Pilots were found to stretch a flight duration beyond that point allowed by the available fuel. Pilots estimated fuel consumption erroneously and failed to use fuel consumption rates provided in manuals. Planning for adverse weather, both during in-flight planning and in preflight planning, are both inadequate. Attention to preflight inspections is deficient as found in many accidents, in particular leading to takeoff with partially full or some empty tanks.

ACCIDENT CAUSES IN GENERAL. Nearly all the accidents analyzed had multiple causes. In most of the accidents, recovery was possible after the first pilot error. Systems and component malfunctions appeared in some of the accidents classified as pilot error, and the combination of mechanical cause and pilot error led to the accident. Attention to cockpit familiarization is deficient, including that for highly experienced pilots. Attention to checklists, applicable to preflight inspections and several phases of flight, is not observed.

QUALIFICATIONS OF THE ACCIDENT PILOTS. The accident pilot group consisted of pilots who held valid certification and ratings. The certification and ratings showed that there were a high number of commercial professional pilots involved. Those in the preventable accident group who had a current instrument rating were much less in proportion to the total than those who held an instrument rating within the 200 accident sample. The total pilot time indicates that the pilots involved in these accidents generally were not beginners. Those pilots who logged time in type over the last 90 day period prior to the accident had what appears to be a sufficient amount of time in type . There were a high number of pilots (17 of 47) that did not log any time in type in the last 90 days. The pilots involved in these accidents were flying other type aircraft in the 90 days preceding the accidents. These pilots did not practice instrument flying, and in addition, a high proportion had not logged any simulated/actual instrument time.

AIRCRAFT MAKES AND MODELS. Analyses of aircraft found in earlier years to be high and low involvement appear in the present study in about the same proportions.

SEGREGATION OF PREVENTABLE ACCIDENTS. The application of countermeasures to the accidents took the form of both cockpit standardization and pilot restrictions. A total of 47 accidents of the 200 sample accidents were rated as preventable and comprise the countermeasures data base. The countermeasures accidents generally conform to the larger group in most characteristics such as environment, flight phase, and severity. The accidents not included in the preventable group comprise about three-fourths of the total and would be difficult to suppress. They are less related to cockpit design and pilot familiarization than to general uncertainties of human factors. The proportion of night accidents in the countermeasures group did show a significant increase, with 15 occurring between 8:00 p.m. and 5:00 a.m. However, in regard to pilot qualifications, the countermeasures cases show a lower level. Several examples illustrate the degradation. In the 15 night accidents, six of the pilots had not logged night flying in the prior 90 days. Only six of the pilots in the countermeasures group were instrument rated, and a high proportion (45 percent) had flown other type aircraft. About one-third had not logged any time in type in the prior 90 days.

COST ANALYSIS FINDINGS.

COST ESTIMATING DATA. Use of the standardized cost values promotes comparability of cost results and was adopted. Attempts to collect actual cost data were abandoned when much of the data proved to be unobtainable and the balance contained unreliable figures. In any event, the value of a statistical life and the number of fatalities cause the more precise values of injuries, aircraft damage, and property loss to be overwhelmed in the results. The value of a statistical life is highest when determined by the value to self and others approach but this value is most frequently used in airplane accident studies and was used here, taken at $530,000.

AVERAGE ACCIDENT COSTS. Costs are provided for each preventable accident. They are aggregated by category of accident and by countermeasure. They are also presented by level of accident severity since these are the crucial values for extrapolating costs from the accident sample to the full NTSB data base. The results for accidents preventable by standardization are:

Fatal accident	$900,200
Severe injury accident	60,900
Minor injury accident	21,400
Property damage only accident	9,040

The most significant variable in the accident costs is the number of occupants in the airplane. This is true not only for fatal accidents but also for severe injuries, where at $38,000 each, personal injuries are likely to be for greater than the dollar value of the aircraft. Many of the fatal injury accidents include costs of severe injuries as well, this being the data item that shows many survivors in fatal accidents.

INCREASE IN AIRCRAFT SALES AND PILOT STARTS.

LONG TERM TRENDS. In the long term, aircraft sales are in a steady upward trend and safety, expressed as an accident rate, is improving. While the direct consequence of aircraft sales to safety is not demonstrable, there nevertheless may be a contribution of safety. Safety improvements are part of the environment in which the industry prospers. New pilot starts are more variable in a statistical sense.

SHORT TERM TRENDS. No correlation leading to positive findings could be established when various approaches were attempted. An apparent correlation of aircraft sales to the accident rate for 1972-79 failed to be confirmed when the time period was extended only to 1970-80. Various plots of the data, as for example, using sales for one year subsequent to accidents, do not disclose any relationship that is consistent. The clearest correlation was found for aircraft sales and real Gross National Product at a level not matched in any other attempts to establish correlation. One explanation for the results may be the erratic behavior of the aircraft sales data where several poor years follow the period when sales grow beyond the long term trend.

ACCIDENT COST REDUCTION BY STANDARDIZATION.

INTRODUCTION OF NEW DESIGN AIRCRAFT. The implementation of standardization is expected to be achieved as modifications to existing designs and as new designs enter the active general aviation fleet. No retrofitting of aircraft is assumed. With a rational estimating procedure, the fraction of new design aircraft is 13.7 percent after five years and 36.5 percent after ten years.

COST REDUCTION AMOUNTS. As standardization features are phased into general aviation designs the benefits over the first few years are insignificant. The cost reductions then begin to mount as the proportion of new design builds up. At the fifth year the cost of the suppressed accidents is slightly under $2 million. At the tenth year the amount reaches just over $11 million, and the annual gains continue to increase. The second $11 million would be realized after just four more years.

THE ALTERNATIVE APPROACH OF PILOT RESTRICTIONS.

PILOT QUALIFICATIONS. The credentials of the pilots of the sample accidents were found overall to be satisfactory, and many very high time and higher certificate pilots were in the group. Both the novice and experienced pilots committed errors of the same kind, including deficient conditioned reactions, and exhibited a lack of cockpit familiarization. The weakest area of pilot qualifications is in the low time in night flying and in instrument flying. The possibility of a new series of certificate endorsements or mandatory additional requirements for the award of certificates presents a large administrative burden. Such measures might have a dampening effect on the growth of general aviation.

PROPOSED COCKPIT FAMILIARIZATION EXAMINATION. A proposed written examination to be used by fixed base operators is proposed. The intention is that such an examination would be issued by the FAA as part of its accident prevention program and would be of an advisory nature. A brief survey of FBOs indicates that their reception to the examination would be favorable. The examination would be structured to force an applicant for a rental aircraft to search the pilot manual and to examine instruments and controls. Typical questions and problems that might be used in the examination are presented in the report.

CONCLUSIONS.

Analysis of general aviation accidents over the most recent five-year period shows a continuity with early investigations. Despite the downward trend in the accident rate, the occurrence of accidents related to mismanagement of fuel and improper operation of powerplant and powerplant controls remains a burden on the aviation community.

The prospects for actually preventing some of these accidents appear favorable since cockpit arrangements having non-standardized features clearly caused pilot difficulties in emergencies. The magnitude of costs associated with accidents rated as preventable is substantial. The amounts are expected to be in excess of the costs to implement standardization, although the latter must yet be determined.

Initially the measures to improve standardization and to assure familiarization of the pilot to the cockpit should concentrate on the fuel system. This is because mismanagement of fuel accidents were about three times as numerous as those in the powerplant control category (among the preventables), and thus offer better prospective rewards.

The proposal for improving pilot familiarity with cockpit arrangements is low cost and could be put into practice without delay. Mandatory pilot restrictions would be burdensome and could be held in abeyance while the effectiveness of an advisory approach would be monitored.

Several techniques evolved in this study were found to be efficacious and could be used on a broader scale. In particular, the sampling procedure with its optimal allocation of variance, enabled the selection of a workable sample for detailed analysis. The technique evolved for determination of accident preventability is a step toward objective analysis of a difficult problem.

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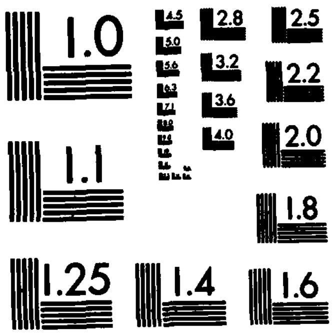

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GLOSSARY OF TERMS

Fuel Starvation: The interruption, reduction, or complete termination of fuel flow to the engine although ample fuel for normal operation remains aboard the aircraft.

Diverted Attention From The Operation of Aircraft: Refers to the failure of the pilot to give the degree of attention required, under the circumstances, to the operation of the aircraft.

Improper Operation of Powerplant and Powerplant Controls: Improper operation of the powerplant from a mechanical standpoint, through improper use of throttles, supercharger, cowl flaps, carburetor heat, mixture controls, propeller controls, etc., under the conditions and circumstances involved.

Improper In-flight Decisions or Planning: The failure to use good judgment or follow good operating procedures while in flight. An example is the failure to refuel enroute when reasonable prudence would require it.

Inadequate Supervision of Flight: Refers to cases where a pilot in command fails to exercise the degree of supervision required by the circumstances. Includes failure of the pilot in command to take over controls in time to prevent an accident.

Lack of Familiarity with Aircraft: Refers to lack of experience with the aircraft involved for the type of operation attempted. It is not used interchangeably with attempted operation beyond experience/ability level as it is more specific and could apply to a pilot of broad experience.

Mismanagement of Fuel: This cause/factor is supported by one or more of the following: (1) inadequate preflight preparation and/or planning; (2) fuel exhaustion, or (3) fuel starvation.

Spontaneous - Improper Action: A reflex type action that may not have a logical explanation.

Fuel Exhaustion: Exhaustion of useable fuel from all tanks.

Cockpit Standardization: Means any universally adopted approach to instrumentation and controls which involves location, operation and/or interpretation.

Pilot Restrictions: Measures taken to assure that a pilot is familiar with the cockpit arrangement, instrumentation, and controls, and with the aircraft characteristics of a particular make and model so that it may be safely flown in the intended use.

Population of Cases: Refers to the 2011 pilot error, mismanagement of fuel and improper operation of powerplant and powerplant control accidents within the five year (1975-1979) span.

Sample of Cases: Refers to the 200 randomly selected (within severity strata) accidents for study from the population.

Countermeasure Cases: Refers to the 47 accidents identified in the study which have been selected as preventable by standardization, preventable pilot restriction, or both.

Recency of Experience: The flight time in type logged by the pilot in command at the time of the accident over the 90 day period previous to the accident.

APPENDIX A
AIRCRAFT MANUFACTURER/MODEL/SERIES DISTRIBUTION
202 ACCIDENT DATA BASE

This Appendix is complete through 188 cases, with the following 12 outstanding cases yet to be received, replaced or dropped:

1975

3-0005
3-1140
3-2490
3-4157

1976

3-0883

1977

3-2510
3-3148

1978

3-0462
3-1427
3-3127
3-4216

1979

3-1838

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
PIPER	SUBTOTAL	PA-18	95	1956	1	28	4
		PA-22	108	1961	1		
			108	1963	1		
			135	U	1		
			150	1955	2		
			160	1958	1		
	SUBTOTAL	PA-22			6	49	12
		PA-23	150	1956	1		
			150	1957	1		
			160	1960	1		
			250	1962	1		
			250	1964	1		
			250	1978	1		
	SUBTOTAL	PA-23			6	26	23
		PA-24	180	1959	1		
			180	1961	1		
			180	1962	1		
			250	1959	1		
			250	1961	1		
			250	1964	1		
			250	1965	1		
	SUBTOTAL	PA-24			7	41	17

MANUFACTURER	MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
	PA-25	150	1960	1		
		235	1965	2		
		235	1969	1		
SUBTOTAL	PA-25			4	42	10
	PA-28	140	1965	1		
		140	1966	1		
		140	1967	1		
		140	1968	2		
		140	1972	1		
		140	1974	1		
		140	1977	1		
		151	1976	1		
		151	1977	1		
		180	1963	2		
		180	1966	1		
		180	1968	1		
	PA-28R	180	1969	1		
		180	1973	1		
		180	1975	1		
		181	1976	3		
	PA-28R	200	1975	1		
		235	1974	1		
SUBTOTAL	PA-28			22	183	12

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
	SUBTOTAL	PA-31		1968	1	16	6
		PA-32	260	1965	1		
			260	1969	1		
			260	1974	1		
			300	1967	1		
			300	1974	1		
	SUBTOTAL	PA-32			5	16	31
	SUBTOTAL	PA-38	112	1978	1	7	14
	SUBTOTAL	J-3	CUB	1946	2	16	12
PIPER	SUMMARY				55	424	13
CESSNA							
		150	F	1966	1		
			G	1967	4		
			H	1968	1		
			J	1969	1		
			L	1972	1		
			M	1976	1		
			M	1977	2		
	SUBTOTAL	150			11	237	5

MANUFACTURER	MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
SUBTOTAL	152		1978	1	42	2

MANUFACTURER	MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
SUBTOTAL	170		1948	1	9	11
	172	C	1962	1		
		D	1963	1		
		E	1966	2		
		K	1970	1		
		L	1972	1		
		M	1976	2		
SUBTOTAL	172			8	109	7
SUBTOTAL	175	B	1961	1	9	11
	177		1968	1		
		A	1969	1		
		G	1972	1		
		B	1976	1		
		RG	1976	1		
		RG	1978	1		
SUBTOTAL	177			6	44	14
	180	SKYWAGON	1976	1		
			U	1		
SUBTOTAL	180			2	20	10

MANUFACTURER	MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
	182	C	1960	1		
		F	1963	1		
		P	1972	1		
		P	1973	1		
SUBTOTAL	182			4	79	5
SUBTOTAL	185	A	1962	1	10	10
SUBTOTAL	195		1950	1	1	100
	P206	A	1966	1		
	U206	F	1974	1		
	TU206	F	1974	1		
SUBTOTAL	206			3	16	19
	210		1960	1		
		CENTURION	1967	1		
			1969	1		
		L	1972	2		
		CENTURION	1973	1		
	T210		1973	1		
			U	1		
SUBTOTAL	210			8	36	22

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
		310	G	1962	1		
			H	U	1		
	SUBTOTAL	310			2	16	12
	SUBTOTAL	320	E	1966	1	5	20
	SUBTOTAL	336	SKYMASTER	1963	1	1	100
		T337	B	1967	1		
			C	1968	1		
	SUBTOTAL	T337			2	12	17
CESSNA	SUMMARY				53	576	9
BEECH							
		D18	S	1946	1		
		E18	S	1956	1		
			S	U	1		
	SUBTOTAL	18			3	18	17
	SUBTOTAL	A19		1968	1	7	14

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
	SUBTOTAL	A23-24	MUSKETEER	1966	1	2	50
		B24R	SIERRA	1974	1		
		C24R		1977	1		
	SUBTOTAL	24			2	8	25
		G35		1956	1		
		H35		1947	1		
		H35		1957	2		
		M35		1960	1		
	SUBTOTAL	35			5	45	11
	SUBTOTAL	A36		1977	1	9	11
	SUBTOTAL	BE65		1966	1	3	33
		95		1959	2		
		B95	A	1959	1		
		D95	A	1965	1		
	SUBTOTAL	95			4	11	36
	SUBTOTAL	100	A	1972	1	1	100
BEECH	SUMMARY				19	104	18

MANUFACTURER	MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
GULFSTREAM AMERICAN (GRUMMAN, AMERICAN)	AA1	A	1969	1		
		A	1971	1		
		A	1972	1		
		A	U	1		
SUBTOTAL	AA1	A		4	11	36
SUBTOTAL	AA1	B-TR2	1976	1	26	4
	AA5	A	1977	1		
		A	U	1		
SUBTOTAL	AA5	A		2	3	67
SUBTOTAL	G21	A	1942	1	2	50
SUBTOTAL	G164	A	U	1	21	5
GULFSTREAM AMERICAN SUMMARY				9	63	14

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
AERO COMMANDER							
	SUBTOTAL	A9	B	1968	1	1	100
		500	S	1970	1		
			S	1972	1		
	SUBTOTAL	500	S		2	2	100
	SUBTOTAL	560	A	1955	1	2	50
		600	S2R	1973	1		
			S2R	1974	1		
	SUBTOTAL	600	S2R		2	7	29
AERO COMMANDER	SUMMARY				6	12	50
BELL		47G2		1958	1		
		47G2		1964	1		
		47G2		1969	1		
	SUBTOTAL	47G2			3	14	21
	SUBTOTAL	47G3B		1961	1	4	25
	SUBTOTAL	MK5A		1975	1	1	100
BELL	SUMMARY				5	15	33

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
BELLANCA	SUBTOTAL	7KCAB		1975	1	2	50
	SUBTOTAL	8KCAB		1973	1	3	33
	SUBTOTAL	14	13	U	1	4	25
		17	30	1970	1		
			31TC	1969	1		
	SUBTOTAL	17			2	19	10
BELLANCA	SUMMARY				5	28	18
MOONEY							
		M20		1955	1		
			E	1964	1		
			G	1968	1		
	SUBTOTAL	M20			3	29	10
MOONEY	SUMMARY				3	29	10

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
NAVION		A		1946	1		
		A		1947	1		
	SUBTOTAL	A			2	9	22
	SUBTOTAL	B	Super 260	1951	1	3	33
NAVION	SUMMARY				3	12	25
DEHAVILLAND							
	SUBTOTAL	DH82A		1941	1	2	50
	SUBTOTAL	DH104	DOVE	U	1	1	100
DEHAVILLAND	SUMMARY				2	3	67
FAIRCHILD HILLER							
	SUBTOTAL	PC-6	C-H2	1966	1	1	100
	SUBTOTAL	1100		U	1	3	33
FAIRCHILD HILLER							
	SUMMARY				2	4	50
HUGHES	SUBTOTAL	269	B	U	1	12	8
	SUBTOTAL	369	C	1973	1	5	20
HUGHES	SUMMARY				2	17	12

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
MAULE	SUBTOTAL	M-4	210	1965	1	3	33
	SUBTOTAL	M-5	220	1974	1	1	100
MAULE	SUMMARY				2	4	50
TAYLORCRAFT		BC12D		U	1		
		BC12D	85	1949	1		
	SUBTOTAL	BC12D			2	4	50
TAYLORCRAFT	SUMMARY				2	4	50
VOLKSPLANE	SUMMARY	VP1	473	1973	2	3	67
AEROSPATIALE	SUMMARY	SA318C		U	1	1	100
AEROSTAR	SUMMARY	600		1969	1	1	100
BEAGLE	SUMMARY	B206	S	1968	1	1	100
BEDE	SUMMARY	BD	5B	U	1	1	100
BREEZY	SUMMARY	RLU	1	1973	1	1	100

MANUFACTURER		MODEL	SERIES	MODEL YEAR	NO. OF A/C IN STUDY SAMPLE	NO. OF SIMILAR A/C IN NTSB DATA BASE	% OF DATA BASE REPRESENTED BY STUDY
DAVIS	SUMMARY	D1W		1933	1	1	100
LUSCOMBE	SUMMARY	8E		U	1	3	33
McCOLLOUGH	SUMMARY	T-1		1970	1	1	100
MITSUBISHI	SUMMARY	MU-2B	30	1967	1	1	100
PIAGGIO	SUMMARY	P136		U	1	1	100
PRESLEY	SUMMARY	B-8		1976	1	1	100
ROCKWELL COMMANDER	SUMMARY	114		U	1	2	50
STEARMAN	SUMMARY	A75N1		1941	1	2	50
STEEN	SUMMARY	SKYBOLT		1977	1	2	50
STINSON	SUMMARY	108	3	1948	1	3	33
STOLP	SUMMARY	STAROWTER	SA 300	1976	1	1	100
VARIVIGGIN	SUMMARY				1	1	100
WITTMAN	SUMMARY	W	10	U	1	1	100
SUMMARY ALL AIRCRAFT					188	1323	14

APPENDIX B

FBO WRITTEN TEST

PURPOSE:

This quiz is designed to aid a pilot in understanding the aircraft he flies. Although no attempt is made to cover in depth all information contained in the typical Owner's Manual, this booklet will provide a review of the basic information a pilot should know before taking off on a cross-country flight. Since the questions are designed to be answered in an open book fashion, no minimum passing score is set, although it is assumed that a pilot holding at least a private license would score high. It is suggested that, in addition to the review provided by this booklet, a thorough, periodic review be made of the Owner's Manual.

INSTRUCTIONS:

Since this is an open book test, you may use any book which will provide you with a correct answer. The Owner's Manual for the aircraft you plan to rent is required, and the Airman's Information Manual is suggested. All answers concerning aircraft performance and limitations should be obtained from the Owner's Manual for the aircraft you plan to fly. If you find a question not applicable to this aircraft, simply omit it. If you are unable to locate the answer to a given question, we suggest you discuss it with the fixed base operator along with any questions answered improperly.

NAME ________________________ DATE ________

MAKE ____________ MODEL ________ AIRMAN'S CERT. No ______ HP ______

RATINGS ________________________

TOTAL TIME __________ LAST 90 DAYS ________ TIME IN TYPE ______

★ ★ ★

1. What is the normal climb-out speed? ....
2. What is the best rate of climb speed? ....
3. What is the best angle of climb speed? ....
4. What is the maximum flap-down speed? ....
5. What is the maximum gear-down speed? ....
6. What is the stall speed in a normal landing configuration? ......
7. What is the clean-stall speed? ....
8. What is the approach-to-landing speed? ....
9. What is the maneuvering speed? ....
10. What is the red-line speed? ....
11. (Multi engine only) What is the VMC? ....
12. What is the estimated TAS at 5,000 ft. and 65% power? ....
13. What RPM or combination of RPM and Manifold Pressure yields 65% power? .... RPM & .... MP
14. How many gallons of fuel are used per hour at 65% power? ....

GAI®

15. How many usable gallons of fuel can you carry?

16. Where are the fuel tanks located, and what are their capacities?

Main tank .... gallons ....
Left tank .... gallons ....
Right tank .... gallons ....
Rear tank .... gallons ....
Auxiliary tank #1 .... gallons ....
Auxiliary tank #2 .... gallons ....

17. (Multi engine only) In the event an engine fails, can all on-board fuel be fed to the running engine? .... If yes, explain how: ....

18. With full fuel load at 65% power, at 5,000 ft., allowing a 45 min. reserve, what is the maximum duration (in hours)? ....

19. What is the octane rating of the fuel used by this aircraft? ....

20. How do you drain the fuel sumps? ....

21. What brand of oil is being used? ....

22. What weight of oil is being used? ....

23. Is it detergent or non-detergent oil? ....

24. How many quarts of oil in the oil sump are recommended for a three-hour flight? ....

25. What is the make and horsepower of the engine(s)? .... Hp.

26. Is the landing gear fixed, manual, hydraulic, or electric? .... If retractable, what is the back-up system for lowering the gear? ....

27. How many people will this aircraft carry? ....

28. What is the maximum allowable weight the aircraft can carry in the baggage compartment(s)?

Rear .... lbs.
Front .... lbs.
Belly .... lbs.
Left engine nacelle .... lbs.
Right engine nacelle .... lbs.
Total .... lbs.

29. What take-off distance is required to clear a 50 ft. obstacle with a gross weight at a pressure altitude of 5,000 ft. and 75 degrees (F)? (Assume no wind and a hard surface runway.) .... ft.

30. What would the answer to number 29 be if the take-off were made from a sea level pressure altitude? ....

31. Would high humidity increase or decrease this distance? ....

32. How do you find pressure altitude? ....

33. What is your maximum allowable useful load? (Check the weight and balance data in the aircraft, not the Owner's Manual.) .... lbs.

34. Solve the weight and balance problem for the flight you plan to make. If you plan to fly solo, solve for a 170 lb. passenger in each seat. Does your load fall within the weight and balance envelope? .... What is your gross weight? .... lbs.
If you solved the problem contemplating 170 lb. passengers in each seat, how much fuel could you carry? ....
Where? ....
If you could carry full fuel how much baggage could you carry? .... lbs. Where? ....